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GROUNDWATER QUALITY AND POLLUTION ASSESSMENT FOR MONTANA STATEWIDE 208 AREA

- PRELIMINARY DRAFT -

For

STATEWIDE 208 PROGRAM
WATER QUALITY BUREAU
ENVIRONMENTAL SCIENCES DIVISION
DEPARTMENT OF HEALTH AND ENVIRONMENTAL SCIENCES
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March, 1978

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INTRODUCTION

Groundwater is widely used in Montana as a source of municipal water for domestic purposes for stock, irrigation, industry, and other uses. Wells are used in about 130 of Montana's 175 communities with public water supply systems. There are an estimated 75,000 to 125,000 wells in Montana that supply water. In many areas, groundwater is the only available water source and much of Montana's farming, ranching and industry depends on wells. Although groundwater in Montana, to date, has been relatively free of pollution, increasing development of mineral resources, increases in population, additional industrialization, changes in agricultural practices within the state have created problems with groundwater and have caused groundwater pollution in some areas.

The portion of Montana evaluated in this investigation (Figure 1) includes 41 counties comprising 106,947 square miles. Sources of groundwater pollution in Montana include the mineral fuels industry, the mining industry, municipal wastes, forest products, industry, industrial wastes, agricultural practices, domestic sanitary wastes, and a host of miscellaneous problems from a variety of sources. Many groundwater pollution problems are minor in scope; however, in many areas there are substantial pollution problems.

This report is written under a contractual agreement between the Montana Water Quality Bureau, Department of Health and Environmental Sciences, under funding provided as part of Section 208 of the Federal Water Pollution Control Amendments of 1972. This effort is part of a larger statewide water quality management program administered by the Water Quality Bureau. The investigation extended from July, 1977 to February, 1978, was principally

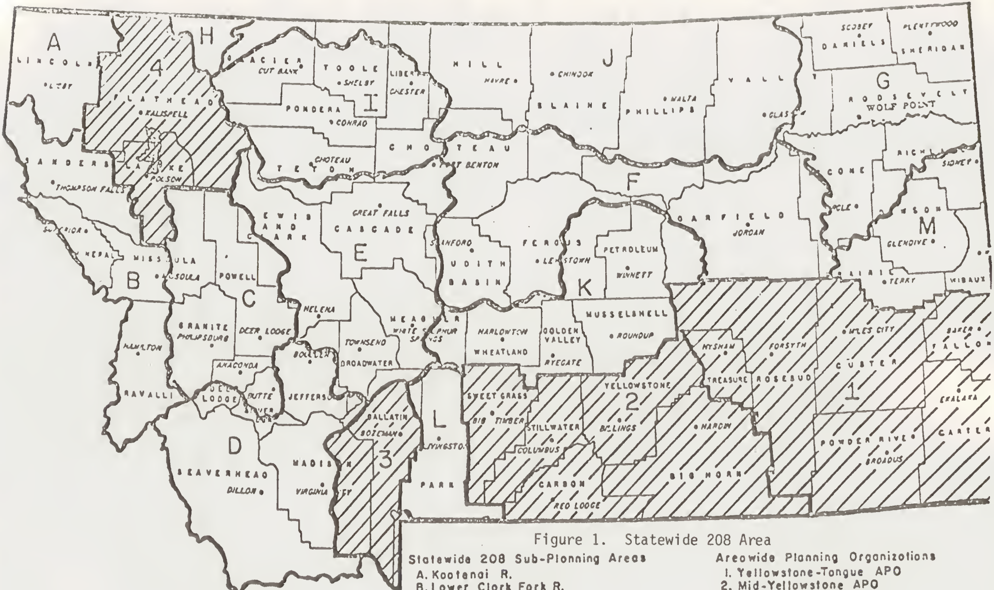

Figure 1. Statewide 208 Area

Statewide 208 Sub-Planning Areas

A. Kootenai R.
B. Lower Clark Fork R.
C. Upper Clark Fork R.
D. Upper Missouri R.
E. Missouri-Sun-Smith R.
F. Mid-Missouri R.
G. Lower Missouri R.
H. St. Mary R.
I. Marias R.
J. Milk R.
K. Musselshell R.
L. Upper Yellowstone R.
M. Lower Yellowstone R.

Areawide Planning Organizations

1. Yellowstone-Tongue APO
2. Mid-Yellowstone APO
3. Blue Ribbons APO
4. Flathead APO

based on examination of information from federal and state agencies and interviews throughout the state and neighboring states and provinces. This included discussions with numerous persons from federal, state and private organizations and some examination of groundwater pollution problems in the field.

Specific objectives of this investigation were:

1. Assemble and evaluate existing groundwater quality data available for the Statewide 208 Area. This involved collection and assembly and entry of these data into a computerized data processing system.

2. Summarize groundwater problems in the Statewide 208 Area to provide a complete inventory of all existing groundwater pollution in Montana and the status of these pollution problems.

3. Assess the long-term potential for groundwater pollution in Montana from a variety of sources including subdivisions, mineral fuels, mineral commodities, and industrial developments. This involved determination of probable developments in Montana and potential future groundwater pollution.

4. Assessment was made of the monitoring and sampling activities in Montana to determine if these activities were suitable, met the needs of Montana and provided a good assessment of groundwater conditions in Montana.

5. Assessment of existing laws, regulations and guidelines that affect groundwater quality in Montana.

6. Development of management and control strategies to correct groundwater problems in the Statewide 208 Area and prevent future groundwater pollution.

ACKNOWLEDGEMENTS

Numerous individuals provided assistance and information for this report. The inventory of current groundwater pollution problems was developed from contacts with county sanitarians in the Statewide 208 Area, district rangers of the U.S. Forest Service, from the Montana Water Quality Bureau, Montana Bureau of Mines and Geology, Montana Department of State Lands, and the Montana Fish and Game Department. Information on agricultural impacts and irrigation impacts were supplied by individual irrigation equipment suppliers, U.S. Soil and Conservation Service personnel, and personnel from Montana State University. Personnel from the Oil and Gas Commission provided information on current water usages in the petroleum and natural gas production and on brine injection, secondary recovery, and handling of brackish and brine water separated from oil. Assembly of groundwater data was assisted by Marvin Miller at the Montana Bureau of Mines and Geology, and by Gary Rogers and Randy Holm from the Department of Community Affairs who provided assistance in developing computerized groundwater mapping and building computerized groundwater files used in this report. Mr. Will Garvin assisted in interviewing persons and suppliers on trends and uses in irrigated agriculture in Montana. Special thanks to the dynamic duo, Carol Clough and Luanne Gilder withwhom the typing of this manuscript proceeded with expedience, kindness, courtesy, diligence and adaptability to innumerable adverse conditions.

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CONCLUSIONS AND RECOMMENDATIONS

Groundwater is abundant and is widely used in the Statewide 208 Area, and a major increase in usage is anticipated in the future. Groundwater quality is variable, being best in western Montana and poorest in northern and central Montana, but generally, except for irrigation and dryland farming, the impact of man's activities is limited. Specific groundwater problems have been investigated; however, regional impacts in many instances are poorly understood.

There are a number of groundwater pollution problems identified in the Statewide 208 Area. Except for irrigation and dryland farming, most problems have impacts that are not major in scope and magnitude.

Correction of existing groundwater problems varies from difficult to impossible, and few existing problems have a potential for cost effective correction or abatement.

The groundwater regulatory framework in Montana is variable in its coverage and intensity; however, there are specific regulations concerning groundwater quality. Saline seep, irrigation, and oil and gas activities have been identified as being important to groundwater quality and have impacts in many parts of the Statewide 208 Area.

Much additional specific groundwater work is needed to understand cause and effect relationships of irrigation, sanitary waste disposal, and some aspects of dryland farming in the Statewide 208 Area. Both intensive and extensive investigations are needed. Specific regulations are needed that directly address groundwater quality and can be used for control of groundwater quality.

The following are specific recommendations and conclusions listed in order of supporting chapter and not in order of importance.

Conclusions

Groundwater characteristics include widespread abundance and slow movement. The vast storage of groundwater, slow movement, and depths make groundwater pollution difficult to detect, and expensive to investigate. A substantial amount of water may become affected before the extent of pollution is determined. Corrective actions often are not cost effective, that is, the cost of correcting a groundwater quality problem is usually not justified by the benefits gained. A strategy for groundwater protection must rely on a preventive approach rather than a monitoring or corrective approach.

A water quality data processing system was developed and used to edit, store, and create maps used in this report. The system, called the Montana Water Quality Records System (MTWQRS), is presently capable of processing data originating with the Montana Bureau of Mines and Geology (MBMG), the Water Quality Bureau (WQB), and STORET. The system is being developed further to handle U.S. Geological Survey (USGS) groundwater data available from that agency's central file in Reston, Virginia. No other agencies or organizations are using this capability. Anyone could use this system for handling water quality data if the information was coded in a compatible format.

Groundwater quality data assembled included approximately 3000 samples analyzed by the Montana Bureau of Mines and Geology (MBMG), the Water Quality Bureau (WQB), and the U.S. Geological Survey (USGS). This data was used to map, by computer plotting techniques, water quality parameters. These parameters are specific conductivity, hardness, sulfate, nitrate plus nitrite, sodium adsoprtion ratio, iron, and zinc. An additional map was plotted showing locations where any of ten metals have been sampled.

These metals are aluminum, cadmium, copper, iron, lead, manganese, mercury, molybdenum, selenium, and zinc.

Major sources of groundwater quality data in Montana are the MBMG, WQB, and USGS. Universities, colleges, the Soil Conservation Service, Department of State Lands, Department of Fish and Game, private organizations and individuals contribute minor quantities of groundwater quality information, most of which is not compatible in its present form for computer processing.

Natural groundwater quality in Montana is generally good to excellent in the western mountainous portion of the state, deteriorating toward the east and north where geological formations are predominantly sedimentary, and precipitation is substantially less. In most areas, groundwater tends to be slightly to substantially poorer in quality than surface waters. Deeper aquifers tend to be poorer in quality; very deep aquifers, penetrated by soil and gas operations, are the poorest quality.

The majority of groundwater supplies in eastern Montana do not meet the recommended water quality criteria for community water systems as defined by the National Interim Primary Drinking Water Standards or the U.S. Public Health Service (1962). However, these waters are being successfully used for municipal, domestic, and livestock purposes.

About two percent of the water used in Montana, or 223 million gallons per day (mgd), are supplied by groundwater. One-half of this is used for irrigation. Domestic water supplies are almost totally dependent on groundwater using 19.6 mgd, while 31 percent of municipal water (41.9 mgd) is supplied by groundwater. An estimated 230,000 persons, or 48 percent of the population of the entire Statewide 208 Area are served by groundwater. Livestock and self-supplied industry use 16.8 mgd and 33.9 mgd respectively. Due to the

large quantities of additional groundwater available, it appears that significant expansion in groundwater use will occur, especially for irrigation and industrial uses.

The regulatory framework covers some activities that relate to groundwater quality such as mining and subdivisions. Regulations involving solution mining of uranium and wastewater injection wells have been proposed, but have not been promulgated. The oil and gas regulations are not detailed and have relatively weak enforcement provisions. There are no specific groundwater quality standards.

The production of oil and gas involves a significant potential for inter-aquifer exchange of groundwater, and a corresponding threat to groundwater quality in affected aquifers. The area of the Overthrust Belt is likely to be intensively explored and developed with over 2,000,000 acres already leased or having lease applications pending.

Large amounts of brine waters are presently being injected for secondary recovery of oil and a substantial increase is expected. The high pressures used and corrosiveness of brine solutions create hazards to well piping integrity. Occasional failures of casing are likely, causing brine solutions to pollute fresh-water aquifers.

Brine pollution problems have occurred in northeastern Montana when brine seeped from pits, killing tress and forced abandonment of several wells. Also in northeastern Montana, shallow groundwater appeared to be degraded by brine leakage, due to brine water flowing from a water injection well. Other problems were reported in the Cutbank area, but were unsubstantiated. Problems documented appeared to be local in nature affecting small tracts of land.

There are four oil refineries and four condensate refineries in the Statewide 208 Area. No groundwater quality problems, due to petroleum refining, are documented in the Statewide 208 Area; however, no investigations of these refineries have been made.

The large network of pipelines and storage facilities for refined petroleum products have resulted in numerous accidental spills of gasoline, diesel fuel and fuel oil. Unprotected buried storage tanks, in particular, have caused, and are likely to cause, contamination of shallow groundwater near gasoline retail stations. Cathodic protection has been effective in preventing corrosion of tanks and piping, but is not used extensively by the oil industry.

The only development of coal in the Statewide 208 Area has been two small subbituminous strip mines near Roundup, and a small lignite strip mine near Savage. Only one coal conversion plant, a 50 MW steam electric generator at Sidney, is presently operating. Strippable coal in the project area consists mostly of lignite in eastern Montana. This is a low BTU, high moisture resource that is presently most economically used near its source. Extensive development in the lignite fields will probably mean an expansion of coal conversion processes in Montana, namely coal gasification, liquification, fertilizer production, and steam electric generation.

No current mining of uranium is taking place in the Statewide 208 Area. It appears that near future possibilities for development of underground or open pit uranium in the project area are poor. Regulations specific to solution mining of uranium are proposed.

Agricultural practices constituted the largest overall impacts to groundwater quality in the Statewide 208 Area. Saline seep, a result of dryland farming practices, had affected an estimated 140,000 acres by 1974,

up from 55,000 acres in 1969. Present acreage affected is estimated to be about 200,000 acres, most of which is located in the glaciated areas of northern and eastern Montana. Besides affecting the useability of land for agricultural purposes, the high concentrations of minerals in shallow groundwater can make water supplies unusable for domestic and livestock drinking. Although there has been considerable work on understanding saline seep problems, there are few on-the-ground attempts at solution or abatement. Solutions require widespread changes in farming practices which may not be as profitable as present crops. Saline seep will continue to be the major source of groundwater pollution in Montana for many years to come because of the widespread nature of this problem, and traditional farming practices.

There is a need for investigation of the impact on groundwater quality in deeper aquifers (100-400 feet) due to saline seep conditions.

Irrigation involves such diverse parameters, such as water application rates, methods, quality, and timing, soils types, crops, and climate, that an overall estimate of irrigation on groundwater quality cannot be concluded. As more land becomes developed, water supplies must be used with more efficiency, with a resulting concentration of salts in soils or groundwater. Understanding of the impact of irrigation on groundwater quality is very primative.

Approximately 85,000 tons of primary nutrients are used yearly in Montana for fertilization of crops. No adverse impacts on groundwater quality due to fertilizers have been documented in the Statewide 208 Area.

Pesticide impacts on groundwater have been limited to accidental back-siphoning of pesticide solutions into wells or impropoer disposal techniques. An estimated two million pounds of pesticides applied to about three million acres has had no documented adverse impact on groundwater quality.

High concentrations of nitrate are present below some feedlots, especially those that are intermittently operated. Proper location, operation and management of feedlots can be significant in prevention of groundwater problems due to percolation of feedlot wastes.

Impacts to groundwater quality from the wood products industry include phenol contamination and measurable quantities of tannins and lignins seeping to shallow groundwater. These problems have been corrected and are not expected in the future.

Only one solid waste disposal site out of 203 in the Statewide 208 Area has had associated groundwater quality problems, that being the Livingston site. High concentrations of minerals, metals, and odor have been noted, these being caused by location in an area having high groundwater.

Municipal wastewater lagoons have an unknown impact on nearby groundwater quality. It is suspected that most groundwaters near lagoons have high nitrate concentrations. The relatively inexpensive protection afforded to surface waters by lagoons seems to outweigh the overall hazard to groundwater quality. Even so, the proper design, construction, location, and operation of lagoons can prevent most groundwater problems.

Land disposal of sanitary wastes is relatively new to Montana, but is increasingly popular. Nitrogen removal varies considerably depending on soil type, design, operation, climate and vegetation cover.

The impacts of septic tanks are generally similar to lagoons or land disposal systems. With the proper design and operation, these systems can be very effective in treating sanitary wastes and have no impact on groundwater quality . In dense residential concentrations; however, septic tank systems can contaminate nearby wells.

Subdivisions of land is greatly increasing in Montana, with projections of 15,000 to 20,000 acres to be approved for subdivision annually in 1978 and 1979. Counties most active in the Statewide 208 Area are Ravalli, Missoula, Powell, Park, Musselshell, Cascade, Lewis and Clark, Jefferson, and Mineral. Two-thirds of new subdivisions were not in compliance with existing law in 1972. Local governments are now responsible for regulation of subdivision design and location; approximately 90 percent of the counties have adopted the state's model subdivision regulations. Only seven counties have adopted any regulatory measures for review of septic tank installation; Cascade, Deer Lodge, Lewis and Clark, Lincoln, Missoula, Park, and Ravalli. The review procedures have been most effective in controlling improper use of septic systems in Missoula and Lewis and Clark counties.

Septic tanks were thought to be causing groundwater degradation in the Helena Valley, in subdivisions southwest of Great Falls, in Melrose, Lincoln, and the Libby Flats. Investigations have shown groundwater contamination in all cases except in Lincoln, but the degree of pollution was relatively small. Well contamination was often the result of high groundwater conditions or improperly constructed wells.

The major efforts in groundwater quality monitoring have been supplied by the Montana Bureau of Mines and Geology, concerning saline seeps and coal mining activites. Otherwise, there has been no technical search for groundwater pollution; all problems have been investigated in response to complaints of polluted water in wells or springs. Only a small percentage of problems have been recognized because of this reponse attitude.

Costs of investigating groundwater pollution are typically prohibitive. Rehabilitation of polluted groundwater involves containment, removal, natural decomposition, or adsorption of pollutants.

A high level of technical competence is necessary to judge whether monitoring systems should be required, where to place these systems, whether they will be cost effective, and how to operate them. Monitoring requirements are site specific and any regulations requiring monitoring should be flexible in that respect.

Recommendations

A preventive approach sould be developed to protect groundwater quality. This includes development of groundwater quality regulations.

The Montana Water Quality Records System should be expanded to include the USGS groundwater data. Other agencies, besides the MBMG and WQB, should be encouraged to centralize water quality data within this system. The system should be periodically reviewed to refine and increase its capabilities.

Detailed investigations are needed to show cause and effect relationships of those land use activities which most severely impact groundwater quality in the Statewide 208 Area. These activities include irrigation, both sprinkler and flood, sommerfallow-crop rotation involved in dryland farming,

the production of oil, brine disposal, subdivisions, mining and mineral processing tailings, and underground storage of refined petroleum products.

Penalties for violation of oil and gas regulations should be strengthened. Additional effort in enforcement of the existing regulations is needed to protect groundwater resources.

The petroleum retail industry should examine protection methods for underground storage tanks. There are proven techniques, that are cost effective, for this protection.

An intensive educational program should be initiated and continued as long as necessary to inform farmers of cost effective approaches to abating saline seep conditions. Economic incentives may be needed to encourage farming practices involving production of less profitable crops.

A cause and effect relationship of irrigation on groundwater quality should be investigated on typical flood and sprinkler systems. This is needed to determine whether irrigation is affecting groundwater quality and what management practices, if any, can be employed to minimize groundwater impacts.

The impact of sanitary wastewater lagoons on groundwater quality should be investigated in several typical cases to determine the impact of these lagoons on groundwater quality.

The Department of Health and Environmental Sciences should pursue an on-going cooperative program (Subdivision and Water Quality Bureaus) to investigate areas of suspected water quality degradation resulting from subdivision activity. This should include continuous monitoring of the physical characteristics of groundwater at the problem areas identified in Section 10 .

The Department of Health and Environmental Sciences should encourage and/or require all counties or other local governments to develop and adopt regulatory measures regarding appropriate design, location, and installation of individual septic systems. More effective enforcement measures should also be considered for proper implementation of existing and future local regulations.

Local governments should be encouraged and/or required to apply the Subdivision and Platting Act in a manner that reflects the intent of the law. This includes identifying and reducing the abuses of exemptions in the act. Greater control of waste treatment system placements and further protection of groundwater quality could be obtained in this manner.

GROUNDWATER CHARACTERISTICS AND POLLUTION

Groundwater is an intimate part of the hydrologic cycle. Its occurrence and abundance is directly related to precipitation and surface water. Nearly all groundwater in the active hydrologic cycle originates by infiltration of rain or melting snow, or by seepage from streams and lakes that lie above the water table. Nearly all the precipitation that falls on the land surface is lost by evapotranspiration, some is lost by runoff in streams, and a small amount percolates downward and enters soils and groundwater systems. The relationship of groundwater to the hydrologic cycle is shown in Figure 2 .

A portion of the precipitation that infiltrates into the soil is evaporated; some is transpired from plants, and some continues percolating downward to deeper groundwater. Rocks and unconsolidated materials that form the shallow strata of the earth generally contain many openings that allow movement and storage of groundwater. These open spaces in rocks and alluvial materials are called voids or pores, and the relationship between the amounts of openings and the amount of solid material is termed the porosity. The term porosity also includes the cracks and fractures in solid rocks and solution cavities in carbonate rocks such as limestone.

Water that has moved downward under the force of gravity eventually will reach a certain level where all the pore spaces are filled with water forming the zone of saturation that extends below the water table. This zone is distinquished from water above the water table in the zone of aeration, where water is held by molecular or capillary forces and air also is present in some pore spaces. Groundwater is continuously replenished by downward percolation of water from precipitation, seepage from irrigation

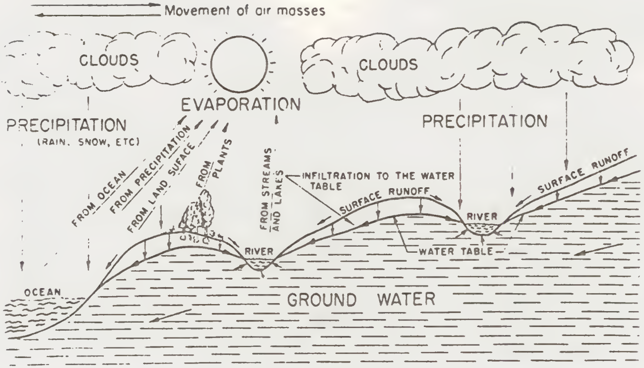

Figure 2 .--Hydrologic cycle.
Source: Konizeski, McMurtrey, and Brietkrietz, 1962

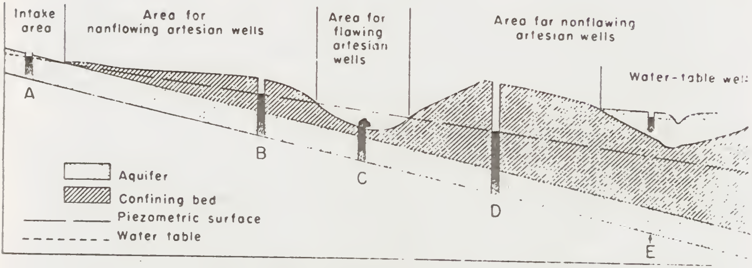

Figure 3. Hypothetical section showing unconfined (water table) and confined (artesian) aquifers. A and E are water-table wells; B and D are nonflowing artesian wells; and C is a flowing artesian well.

Source: Konizeski, McMurtrey, and Brietkrietz, 1962

waters, streams, and ponds, and is depleted by discharge to springs, wells, and streams, and by evapotranspiration.

Water in an underground aquifer may be either under artesian or water table conditions. Any rock formation or stratum that will yield waters in sufficient quantities to be important as a source of supply is called an aquifer. These aquifers are the underground conduits that move water from one area to another. They are composed of either porous or fractured materials and have substantial areal continuity.

Figure illustrates artesian, artesian flowing, and water table (nonartesian) wells. Water is under artesian conditions if it is confined in an aquifer between overlying and underlying relatively impermeable strata. Under these conditions, hydrostatic pressures in the aquifer will raise the water in any well that penetrates the aquifer, to a point above the top of the aquifer (Figure 3). When water is pumped from a well, an artesian aquifer continuously remains saturated, however, pressure within the aquifer decreases. Artesian aquifers are recharged in their outcrop areas or intake areas, and act somewhat similar to large pressure pipeline. Flowing artesian wells occur when an aquifer hydraulic head is greater than the distance to the ground surface (Figure 3).

If water in an aquifer is not confined by overlying impervious strata, the water is under nonartesian, or unconfined conditions. Under unconfined conditions, water pumped from wells drains from earth materials surrounding the well and enters the well.

The water-yielding ability of an aquifer per unit volume is called the coefficient of storage. This is the volume of water that is released from, or taken into storage per unit surface area of the aquifer per unit change

in the component of head normal to that surface. Artesian aquifers have very small coefficients of storage generally ranging from .001 to .00001, whereas, water table aquifers have much higher coefficients of storage ranging from 0.1 to 0.3.

The ease with which water moves through an aquifer is of importance and is related to frictional forces present in the aquifer. Clays, silts, shales, and other fine-grained materials have large surface areas and great frictional resistance. Much more water can move through coarse materials than through fine materials. The ability of water to move through an aquifer is related to its permeability, which is the amount of water that will pass through a unit cross-section of the aquifer under a given pressure differential. The term transmissibility is used to indicate the ability of an aquifer to transmit water through a section measuring a unit width times the entire height of the aquifer under a given pressure differential. Transmissibility, therefore, is equal to permeability times the thickness of the aquifer. In water systems, the higher the transmissibility or the permeability, the greater the amount of water that moves through the aquifer under a given hydraulic gradient (pressure differential between two points).

Groundwater does not remain stationary, but moves in response to the hydraulic gradient in the aquifer and rises and falls reflecting balance between water inflow and outflow in the aquifer. A falling water table indicates discharge is greater than recharge. A rising table indicates recharge is greater than discharge. Aquifers act as huge underground storage reservoirs and it is estimated that in Montana, 90 percent of the fresh water in the state at any time is stored in underground aquifers.

The rate of movement of groundwater in aquifers is extremely slow compared to surface waters. Typical rates of groundwater movement are from less than a foot per day to a few tens of feet per day in very permeable materials. The direction of movements is parallel to the hydraulic gradient, that is, directly from points of high head to points of low head.

Groundwater Pollution

The vast storage of water in underground reservoirs, the widespread presence of this water, its very slow movement, and depth, are all factors that must be considered in pollution of groundwater. Groundwater pollution is difficult to detect, expensive to investigate, and may involve a substantial volume of water before the extent of pollution is determined. Corrective actions often are economically unfeasible, or, if correctable, a long period of time may be required. The physical characteristics of groundwater, its response to pollution, its value as a resource, leads to the important conclusion that a strategy for groundwater protection must rely on a preventive approach, rather than a monitoring and corrective approach. Monitoring systems sometimes provide information as to what has happened in aquifers and may show the beginning of pollution problems. Monitoring, however, yields historical data, that is, information about events that already have happened. Thus, the emphasis on monitoring must be to determine pollution of groundwater as soon as possible, and as close to pollution source as possible. Since there are a large number of potential groundwater sources, the ability to carefully monitor each pollution source becomes an impossible administrative, technical, and financial problem. Groundwater pollution problems are associated with man's activities. Most communities, industries, and other activities are located in valleys along streams. Since most large, shallow groundwater systems are also along streams, this creates maximum opportunities for

groundwater pollution. Unconfined aquifers generally connected to nearby streams, are commonly impacted by pollution problems. The more deeply buried confined aquifers generally are most vulnerable to pollution in their outcrop area only. This somewhat restricts pollution of confined aquifers. A typical groundwater pollution problem (Figure 4) shows the entrance of a pollutant into a groundwater system. To detect this pollution and prevent it from migrating and creating a large volume of polluted groundwater, requires a properly placed monitoring well that is monitored at the right time for the pollutant of interest. It is obvious that a monitoring strategy for groundwater protection requires substantial technical understanding and design. Monitoring must be considered as a supplemental activity with prevention the major focus.

Figure 4. Typical movement of pollutants to groundwater systems (EPA, March, 1972)

GROUNDWATER QUALITY CHARACTERISTICS AND CRITERIA

Water is one of the best solvents known to man and is often called the universal solvent. The world's oceans, river, lakes, springs and wells all contain dissolved substances including salts, metals, and organic compounds and have physical characteristics such as temperature, specific conductivity, color, pH, and turbidity. These characteristics of water combine to form what is called water quality. This characteristic quality is a determinate factor in the suitability of the water for various uses including irrigation, stockwater, public water supply, maintenance of aquatic life, and commercial and industrial uses. It must be emphasized that surface water in streams, lakes and groundwater are all a part of an interconnected hydrologic system. This fact is clearly demonstrated during low-flow periods when streamflow is nearly entirely derived from groundwater. Detailed discussions of chemical characteristics of substances in water are available in many publications such as Hem (1970), Feth (1973), Swenson and Baldwin (1965), and Leopold and Langbein (1960).

Characteristics of the more important water quality parameters are briefly summarized in this report. They provide a framework for understanding natural groundwater quality and water quality pollution problems in Montana.

Water quality criteria have been the focus of much interest and investigations. Studies have examined the influence of specific parameters on uses such as water supply, stockwatering, and irrigation. Development of water quality criteria has related concentrations of specific organic and inorganic substances and physical conditions to water uses with an emphasis on defining toxic or adverse concentrations and conditions.

Increasing use of water by man, together with a great awareness of the interconnection between surface water and groundwater has required understanding and development of criteria suitable for groundwater.

In this section, groundwater characteristics are assessed including the more important inorganic, organic and physical characteristics of groundwater and a description of criteria for various groundwater uses. The understanding, regulation, management, and control of groundwater is related to specific quality characteristics and criteria for various uses. Specific references related to water quality include McKee and Wolf (1963), EPA (1972), Little (1970), Kemp, Little, Sholman and Darby (1973).

Calcium (Ca) and Magnesium (Mg)

Calcium and magnesium are dissolved from almost all rocks and soils, but the highest concentrations are almost always found in water that has been in contact with limestone, dolomite, and gypsum. Decomposition of feldspar minerals also has been shown to be an important mechanism in yielding calcium and magnesium to water. Calcium and magnesium are the principal causes of hardness in water, scale in boilers, deposits in water heaters and pipes, and cause soap to lather with difficulty. Hardness affects the usefullness of water for public water supplies, some industrial uses and is important in aquatic systems. Hardness in water commonly counteracts the toxic effects of substances such as zinc, cadmium, and others. Calcium and magnesium are two major cations found in nearly all natural groundwater systems and directly affects groundwater uses.

Sodium (Na and Potassium (K)

Sodium and potassium are found in all natural waters. Sodium is typically a major cation in some highly mineralized waters inthe western United States. Sodium and potassium have little effect on usefulness of water for many purposes,but waters that contain more than 50 to 100 mg/l of the two substances, may require careful operation of steam boilers to prevent foaming. Waters that contain a high proportion of sodium relative to calcium and magnesium may be unsatisfactory for irrigation. For persons on salt restricted diets, sodium in drinking water is of importance. Sodium is present in nearly all rocks in the earth's crust. Dissolution occurs from feldspar minerals (Hem, 1970), and in sedimentary rocks and can be leached by migrating groundwater. Potassium also is found in igneous rocks, but potassium minerals tend to be more resistant to solution than those of sodium. Potassium is normally found in concentrations much less than sodium in nearly all natural waters. Sodium, calcium, and magnesium generally comprise the majority of cations in natural groundwaters.

Sulfate (SO_4)

Sulfate is present in most natural waters and can be present in high concentrations due to solubility of sulfate-bearing minerals such as gypsum.

ELEMENTS

				effect	no effect		Montana Average	Montana Range
Aluminum (Al)	1-5 [a131]	5 [d309]	10 [a130]	.07 [a130]	.05 [a179]	.074 [c8]	.2	<.1-2.8
[illegible]	— — [a139]			3.5 [a139]				
Arsenic (As)	.05 [e]	.2 [d430]	.10 [d338]	1.1 [a141]	1.0 [a141]	.043 [c8]	.025	<.001-.090
Barium (Ba)	1.0 [d37]		1.0 [a13]	12 [a143]	5 [a142]		<.1	<.1-.4
Beryllium (Be)	— — [a38]	— — [a45]	.10 [d339]	.15 [a146]	.011 [a146]	.0002 [c8]	<.005	<.005-.01
Boron (B)	5 [d39]	50 [d310]	.75 [d339]	5000 [a148]	2000 [a148]	.101 [c8]	.1	<.1-15
Bromine (Br)	— — [118]			10 [a148]	1.0 [a148]			
Cadmium (Cd)	.01 [d80]	.05 [d311]	.01 [d339]	.0005 [d180]	.0004 [d180]	.0095 [c8]	.006	<.002-.055
Calcium (Ca)		1000 [a151]				57.1 [d306]	65.3	15-216
Cerium (Ce)	— — [a37]			.14 [a157]				
Chlorine (Cl)	2 [a161]		3.0 [a161]	.03 [a162]	.002 [d35]			
Chromium (Cr)	.05 [e]	1.0 [d311]	.10 [d339]	1.2 [a163]	.05 [d180]	.0097 [c8]	<.02	<.02-.02
Cobalt (Co)	— — [a166]	1.0 [d311]	.05 [d339]	10 [a167]	1.0 [a167]	.001 [d306]	<.03	<.03-.03
Copper (Cu)	1.0 [a169]	.5 [d312]	.1 [a171]	.025 [a171]	.02 [a171]	.0138 [d306]	.01	<.01-.23
Gold (Au)	— — [a181]			.40 [a183]				
Iodine (I)						.046 [d306]		
Iron (Fe)	.3 [a184]	— — [d136]	5.0 [d339]	.2 [a203]		.044 [d306]	<.05	<.05-.29
Lanthanum (La)	— — [a186]	— — [a306]		.15 [a206]				
Lead (Pb)	.05 [e]	.1 [d313]	5.0 [d339]	.1 [a208]	.03 [d181]	.023 [c8]	<.05	<.05-.07
Lithium (Li)	5 [a210]		.075 [d339]					
Magnesium (Mg)	30-125 [a211]	500 [a211]	24 [a211]	300 [a212]		14.3 [d306]	17	<1-175
Manganese (Mn)	.05 [a216]	10 [a218]	.2 [d339]	2.2 [a215]	1.0 [a215]	.029 [d306]	<.01	<.01-.10
Mercury (Hg)	.002 [e]	.01 [d314]		.008 [a218]	.00005 [d]			
Molybdenum (Mo)		— — [d136]	.01 [d339]	70 [a221]		.068 [c8]	.030	<.001-.299
Nickel (Ni)	1.0 [a481]		.20 [d339]	5 [d181]		.019 [c8]	<.02	<.02-.03
Oxygen (O)	≥ 4 [d14]				— — [d181]		10.2	7.4-22
Palladium (Pd)				7 [a234]				
[illegible]	340 [a243]			50 [a243]		4.3 [d306]	3.1	<.1-13
Radium (Ra)	— — [a185]					.05×10⁻⁹ [a250]		
Rubidium (Rb)				14 [a253]				
[illegible]	.01 [e]	.05 [d3]	.02 [d339]	2 [a254]		.000016 [d306]	.004	<.002-.014
Silver (Ag)	.05 [e]	— — [a256]	.05	.003 [a257]		.0026 [c8]	<.05	
Sodium (Na)		2000 [d317]		500 [a259]		55.1 [d306]	40.6	1.0-530
Strontium	— — [a214]	— — [a218]	— — [a174]			.22 [c8]	.2	<.1-1.0
Sulfur (S)				10 [a270]				
Thallium (Tl)					.05 [d256]			
Thorium (Th)				.4 [a286]				
Tin (Sn)	— — [a186]	— — [a186]	40 [a186]	6.0 [a287]	1.2 [a287]			
Titanium (Ti)	— — [a187]	— — [a187]	12 [a187]	20 [a287]				
[illegible]				110 [a290]				
Uranium (U)	5-10 [a]	— — [a191]		2.8 [a152]				
Vanadium (V)	— — [a181]	.1 [d316]	.10 [d339]	4.8 [a292]				
Zinc (Zn)	5 [a194]	25 [d317]	2.0 [d335]	.01 [a293]	.003 [a196]	.04 [c8]	.08	<.001-.16
Zirconium (Zr)		— — [a197]		14 [a298]		.052 [d306]	.03	<.01-.17

PHYISICAL

Color (units)	75 [d63]						7	<5-45
Conductivity			750 [d335]				531	128-2269
pH	5.0-9.0 [d40]		4.5-9.0 [d332]		6.5-8.5 [d]		8.1	6.7-9.4
Residue (Suspended)[1]	[a280]		— — [d332]		25 [d29]			
Residue (Filterable)[2]	500 [a29]	2860 [d34]	500 [d33]				330	82-2361
Temperature	— — [d89]				— — [d151]		9.5	0-27
Turbidity	1-5 [e]				— — [974]		325	75-22000
Gas Saturation					110% [d39]			

BIOLOGICAL

CONCENTRATION EXPRESSED ... ORGANISMS PER 100 MILLILITER

Fecal coliform	1 [e]				.70 [d37]		235	0-4800
Total coliform							181	0-7000

COMPOUNDS

				effect	no effect		Average	Range
[illegible]	— — [a126]	170 [a127]		— — [940]				
[illegible]	— — [a74]	170 [a29]		— — [940]			134	57-399
[illegible]	.5 [d33]			.11 [d187]	.02 [d187]			
Carbonate (CO_3)	20 [d35]			— — [940]			.11	0-13
Bicarbonate (HCO_3)	150 [d46]		172 [a146]	— — [940]		90 [a147]	158	61-500
Carbon Dioxide CO_2	— — [a56]				— — [d133]			1.2-13
Chloride (Cl^-)	250 [a161]	1500 [a161]	100 [a161]		— — [a161]	9 [a161]	10.9	<.5-74
Cyanide (CN)	.01 [d]		.2 [a19]	.05 [d190]	.005 [d190]			
Fluoride (F^-)	1.4-2.4 [e]	1.0 [a191]	1.0 [d339]	2.3 [a191]	1.5 [a191]		.43	<.05-2.4
Hardness as $CaCO_3$	150 [d]		70 [a197]		— — [9141]		191	63-1260
MBAS[3]	.5 [d67]		— — [a198]			<.1 [d190]		<.01-.17
Nitrate (NO_3 as N)	10 [e]	100 [d316]	— — [a]			.9 [a225]	.10	<.01-.69
Nitrite (NO_2 as N)	1 [d73]	10 [d215]	— — [a226]				<.01	<.01-.02
Oil and Grease	0 [d38]	30 [a231]	— — [a231]	.39 [36]				
Phenol (C_6H_5OH)	.001 [a240]	1000 [a240]	50 [a240]	.079 [d191]				<.001-8.4
Phosphate (PO_4 as P)	50 [a240]		60 [a241]		.01 [m]	.087 [d306]	.013	<.001-.05
PCB[4]				.00001 [d177]	.000002 [d177]			
RSC[5]			1.25 meq/L [a81]					
Silica (SiO_2)	50 [a238]		10-50 [a238]		— — [a233]		8	1-32
SAR[6]			8 [a333]				1.2	.10-7.4
Sulfate ($SO_4^=$)	250 [a]	500 [a277]	200 [a277]		— — [a276]	32 [a276]	.30	<10-1254
Sulfide ($S^=$)	.2 [a277]			.017 [d193]	.002 [d193]			

PESTICIDES

Endrin	.0002 [e]	4 mg/kg [d]		2×10⁻⁶ [d186]
Lindane	.004 [e]	88 mg/kg [d138]		2×10⁻³ [d186]
Methoxychlor	.1 [e]	14 mg/kg [d]		5×10⁻³ [d186]
Toxaphene	.005 [e]	4 mg/kg [d134]	— — [d350]	1×10⁻⁵ [d186]
[illegible]	.05 [d17]	35 mg/kg [d140]	— — [d349]	2×10⁻⁵ [d186]
[illegible]		800 mg/kg [d148]		
[illegible]	.1 [e]	20 mg/kg [d140]	20 [a366]	1.0 [937]
2,4,5,-TP Silvex	.01 [e]			1.0 [937]
Aldrin	.001 [d17]	5 mg/kg [d]		8×10⁻⁷ [937]
Dursban		82 mg/kg [d]		6×10⁻⁷ [937]
Fenthion (Baytex)		200 mg/kg [d]		6×10⁻⁷ [937]

Table 1. Summary of Water Quality Criteria

EXPLANATIONS

Source: Botz and Pederson, 1976

DRAFT

Letters and values following criteria indicate reference source and page number for criteria
All values in mg/l unless indicated.
< less than, no following indicates detection limit of Montana State Water Lab using normal procedure with extraction
*Indicates the minimum concentration of a substance for the use specified
1 SS=Total Suspended Solids, 2 TDS=Total Dissolved Solids, 3 MBAS=Methylene Blue Active Substance.
4 PCB=Polychlorinated Biphenyls, 5 RSC=Residual Sodium Carbonate; 6 SAR=Sodium Adsorption Ratio
no concentration limits set on the parameter reference and pg. no given for prose discussion

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It also is formed by oxidation of iron sulfides and is present in high concentrations in some acid mine drainage. Sulfate also can be found in rainfall due to interaction of sulfur dioxide gases and water in the atmosphere. Combustion of fuels, particularly coal, releases large quantities of sulfur dioxide to the atmosphere creating an increased load of sulfate in precipitation in all parts of the United States. Sulfate for domestic water use has a recommended limit of 250 mg/l. Sulfate in excess of this concentration can be a mild diuretic to those persons not accustomed to high-sulfate water, particularly when the sulfate is combined with magnesium. Concentrations in excess of 500 mg/l and 200 mg/l for stock and long-term irrigation, respectively, has been recommended (Table 1). Sulfate is one of the major anions found in most natural groundwater systems.

Chloride (Cl)

Chloride is present in nearly all natural groundwaters and in some areas, chloride can be the major anion in solution. Chloride is present in various rock types particularly sedimentary rocks and evaporite deposits. Most chloride compounds are soluble and can be leached. According to Hem (1970) most igneous rocks do not yield high concentrations of chloride to circulating natural-water systems, thus, areas containing igneous rocks generally have low concentrations of chloride. Another source of chloride, and, in some areas, the most important source is from natural precipitation. In some regions of Montana this is a major source of chloride ions in the system. Chloride also is an important constituent in sanitary wastes and in runoff from irrigated lands. Chloride in high concentrations can adversely affect the industrial use of water by increasing its corrosiveness. Criteria for chloride concentration in groundwater (Table 1) indicates a limit of 250 mg/l for drinking water,

which is related to the salty taste chloride imparts to water above this concentration. Chloride in high concentrations also can adversely impact stock waters and irrigation waters.

Carbonate (CO_3) and Bicarbonate (HCO_3)

The major source of carbonate in groundwater is from carbonate minerals. Bicarbonate is formed when carbon dioxide and water reacts with carbonate and other rock types. Some carbon dioxide dissolves in rain water and is present in large amounts in decaying organic matter and enters into percolating water. Bicarbonate and carbonate concentrations present in natural waters are related to water pH. Below pH 8.3 (this includes most natural waters) carbonate is present only in small amounts, and bicarbonate is the dominant ion. Above a pH of 8.3, the carbonate ion begins to be present in increasing concentrations, but is seldom a dominant anion. Most groundwaters contain less than 100 mg/l of bicarbonate, however, in some water, such as groundwaters in eastern Montana, the bicarbonate, carbonate concentrations can become in excess of several hundred milligrams per liter.

Bicarbonate and carbonate are the major components in alkalinity of waters which is defined as the ability of water to neutralize a strong acid. Waters with high alkalinities are termed "well buffered" waters in the sense that they tend to maintain a stable pH. Inputs of substances such as strong acids tend to be neutralizing without having any significant impact. Alkalinity is normally not considered detrimental to humans, but is detrimental to some industrial processes, particularly those involved with the processing of food and beverages (McKee and Wolf, 1963). Alkalinity does not seem to have harmful effects upon most aquatic life and is typically antagonistic (counteracts the effects of) towards the toxicities of some metals. According to McKee and Wolf (1963) it is

recognized that the best waters for support of aquatic life are those with pH values between 7 and 8, having a total alkalinity of 100-200 mg/l or more.

Fluoride (F)

Fluoride is present in many natural waters and is utilized in the structure of bones and teeth and has been recognized as an important element in dental hygiene. Sources of fluoride in natural waters are fluoride minerals, which are present in igneous and sedimentary rocks. Fluoride is shown to be present in many hot spring waters from volcanic areas. Most groundwaters contain less than 1 mg/l of fluoride, but in some areas, fluoride is present in high concentrations in excess of 10 mg/l. The National Interim Drinking Water Standards have a maximum limit for fluoride of 1.4 to 2.4 mg/l depending on the average air temperature. Fluoride concentrations above this amount can cause mottled teeth. Fluoride concentrations within recommended limits has been shown to be effective in preventing dental caries.

Nitrogen

Nitrogen occurs in groundwater in a number of forms including nitrate (NO_3), nitrite (NO_2) and ammonia (NH_3). Most nitrogen is derived from biological materials and the species present in groundwater normally are related to the nature of biological decomposition processes. Nitrate nitrogen is considered to be the final oxidized product of decomposing nitrogen-containing matter. Nitrate concentrations in groundwater may indicate presence of decomposing organic matter or sewage. Excess nitrogen in waters is a contributing factor, and, in some cases, the main cause of a condition in infants known as methemoglobinemia (blue babies). The National Interim Primary Drinking Water Standards limit

the maximum concentrations of nitrate-nitrogen for waters used for drinking purposes to 10 mg/l as nitrogen.

Nitrogen also is a macronutrient in aquatic systems and it has been suggested that NO_3 concentrations in excess of 0.35 mg/l may lead to eutrophic conditions in water systems (A. Horpestad, pers. comm., 1977).

Nitrite concentrations are usually low and are a small fraction of the total nitrogen in most waters. Nitrite is readily oxidized to the nitrate in most natural water systems. Ammonia can be present in groundwater systems, but is oxidized to nitrite. Ammonia can be toxic, and, in aquatic systems, concentrations in excess of 0.02 mg/l, may have adverse impacts (EPA, 1972).

Phosphorous (P)

Phosphorous is an essential element in the growth of plants and animals and is a limiting macronutrient in many natural water systems. Phosphorous is found in a number of natural minerals, most importantly, apatite (calcium orthophosphate). Phosphorous is also found in certain phosphate-bearing shales (Phosphoria Formation), and is made available by dissolution of these minerals by groundwater. Phosphorous is also present in sewage, in animal metabolic wastes, and is widely used as a major component in household detergents. It is also widely used as a phosphate fertilizer. The most abundant and common form of phosphorous in groundwater is the orthophosphate ion (PO_4), which is the final dissociation product of phosphoric acid. Phosphate in normal waters usually is much lower in concentration than the criteria for most uses (Table 1), and phosphate is seldom a limiting factor in water use. In natural water systems, phosphate concentrations in excess of .05 mg/l can lead to eutrophic conditions (A. Horpestad, pers. comm., 1977)

Silica (SiO_2)

Silica occurs in sand, quartz, feldspar, and other minerals and is dissolved from practically all rocks. Although many bodies of natural waters contain less than 5 mg/l of silica, few contain more than 50 mg/l. Groundwaters, due to their long and intimate contact with earth materials, typically contain more silica than surface waters. Silica affects the usefulness of water because it causes the formation of scale in boilers creating troublesome deposits during high-pressure applications. Silica is present in all groundwaters, but seldom is present in limiting amounts.

Total Dissolved Solids

In natural water systems, the total amount of dissolved solids in the water often acts as a constraint to suitability of water for most purposes. Dissolved salts and dissolved mineral constituents in water, are termed "dissolved solids". Most waters with less than 500 mg/l dissolved solids - about one quarter teaspoon of salt in each gallon of water - are satisfactory for domestic and some industrial use. Water containing several thousand milligrams per liter of dissolved solids is sometimes successfully used for irrigation where the salts can be readily removed by application of large amounts of water from well-drained soils. Generally, however, waters containing more than about 2000 mg/l are considered unsuitable for long-term irrigation. For public water supplies, it is recommended that the total dissolved solids be maintained at less than 500 mg/l. In Montana, particularly eastern Montana, many public water systems are successfully using waters in excess of 500 mg/l.

Specific Conductivity

Specific electrical conductivity is the capability of an aqueous solution to conduct an electric current. Distilled water is a poor conductor of electricity and depends on dissolved ions in solution to conduct a current.

The concentration of dissolved ions in water therefore, is indirectly measured by electrical conductivity (SC). As the concentration of total dissolved solids increases, specific conductance also increases. There is an excellent relationship between SC and concentration of ionic species in the water expressed in milliequivalents per liter for all waters (Botz, unpub.). For any type of water, this relationship can be used to estimate the concentration of total dissolved solids (TDS) as well as specific cations and anions. The ratio of total dissolved solids to specific conductivity varies somewhat but generally is in the range of 0.6 to 0.8. That is, the total dissolved solids concentration in millgrams per liter is about 0.6 to 0.8 times the value of specific conductance (micromhos) determined in a standard conductance cell. Conductance is the reciprocal of resistance and is reported in units that are the reciprocal of omhs, or mhos. There generally are no specific limitations on the specific conductivity for various water uses as water uses are related to specific ions or to the cumulative total of ions (total dissolved solids). The suitability of water for irrigation, however, is typically related to the conductivity in micromhos and the sodium hazard in the water (USDA, 1969) (Figure 5).

Groundwaters typically have a higher conductivity than do surface waters. This is thought to be a result of the intimate contact of groundwaters with earth materials and more opportunity for the dissolving of substances from the earth.

Hardness

Hardness is a characteristic of water that is widely used and is often associated with the affects observed from the use of soap, or incrustations left by some waters when they are heated. Hardness is due to calcium, magnesium, and other alkaline earth metals, however, most chemical analyses

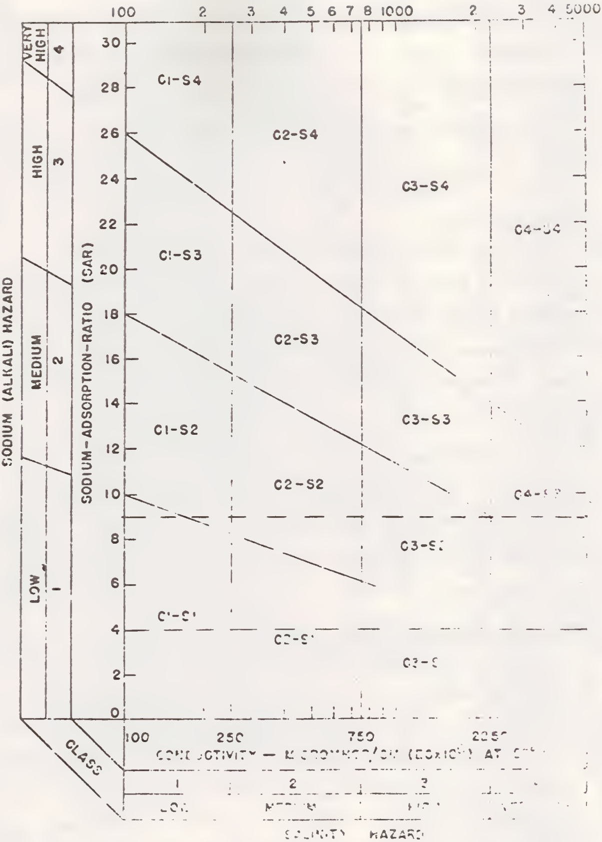


Figure 5. Diagram for the classification of irrigation waters

USDA, 1969

calculate hardness from the concentration of calcium and magnesium and it should more properly be called the calcium-magnesium hardness. Hem (1970) describes hardness as follows:

Hardness as $CACO_3$ (mg/l)	Description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Hardness for ordinary use usually does not become objectionable until it reaches an excess of 100 mg/l. Hardness interferes with many industrial processes particularly involving steam boilers, and can be a problem in domestic use sometimes requiring softening. Hard water requires more soap, is harder on clothes and hands, and measurably shortens fabric life.

For irrigation purposes, hard water reacts favorably with some soils improving the soil structure. As mentioned under calcium and magnesium, hardness in water systems decreases the toxicity of some metals and most waters with good biologic productivity contain significant amounts of hardness.

Sodium Adsorbtion Ratio (SAR)

The sodium adsorbtion ratio expresses the relative ability for magnesium, calcium, and sodium to exchange in soils. Soils with a higher calcium and magnesium percentage tend to have higher permeabilities and better soil structure. Those high in sodium, tend to defloculate, making soils less permeable and less useful for agricultural purposes. With concentrations expressed in milliequivalents per liter, SAR is defined as:

$$SAR = \frac{(Na+)}{\sqrt{\frac{(Ca^{+2}) + (Mg^{+2})}{2}}}$$

Evidence shows that SAR predicts reasonably well the degree to which irrigation waters enter into cation exchange reaction with the soil (Hem, 1970). High SAR values imply a hazard of sodium replacing calcium and magnesium, thus, creating damage to soil structure. SAR is widely used as a measure of the suitability of waters for agricultural soils and generally, SAR values in excess of nine, are marginally useful for irrigation. Relationship between SAR and conductivity are related to the usefulness of various water types for agricultural use in Figure 5 .

pH - Acid and Alkali Balance

The balance between the acids and alkali in solution is known as pH. A pH of 7.0 indicates a neutral water; above 7, the water is alkaline, and below 7, it is acidic. In most natural waters, a pH of 6 to 8 is common. Acid waters are developed in volcanic areas and are common in some mine drainage where pyritic minerals create acidity. For public water supplies, pH limits between 5.0 and 9.0 are recommended, and long-term irrigation pH between 4.5 and 9 are recommended (Table 1). Many chemical and biological reactions are a function of pH and many waters that have been used by man have alterations in the acid and alkali balance. Water pH is, therefore, a good indicator of overall water quality and affects its usefulness for many purposes.

Color

The term color refers to the appearance of water that is free from suspended sediment. Turbid water may have a variety of colors including yellow, red, and brown. However, this apparent color may be removed after the water has been filtered. Some water colors such as those formed by tannins and lignins or the decay of organic matter, yield a yellow to coffee-brown color. Color also is common to some industrial processes such as

wood pulp processing. For domestic use and some industrial uses such as beverages, water should be free from any perceptible color. A recommended limit (USPHS, 1962) for drinking water is 15 CU (color units). A color in water of less than 10 usually is not noticeable. Some dark colored organic waters contain several hundred or more color units. Groundwater can have color for a variety of reasons, including minerals associated with some types of coals, from industrial or municipal wastes, and from natural decomposition of organic materials.

Taste and Odor

Taste and odor are closely associated senses, although, the sense of smell is much more acute than taste. Both measurements are sensitive and personal and lack scientific preciseness. Odors can be caused by a variety of things including dissolved gasses, particularly H_2S gas, decay of organic matter, some microscopic organisms, and from sewage and industrial wastes. For most uses, water should be free of tastes and odors.

Turbidity

Turbidity is an optical property of water normally associated with suspended matter. When a beam of light passes through muddy water, the intensity of the light is reduced and the amount of reduction is a measure of the water's turbidity. Suspended materials, and, in some cases, colloidal materials may be fine suspended particles such as clay, silt, or other materials associated with industrial and domestic waste. Practically all public water supplies that are filtered are free from noticeable turbidity. Most consumers begin to object to water turbidity exceeding 5 JTU (Jackson Turbidity Unit). For many years the standard unit of measurement of turbidity has been the Jackson Turbidity Unit. Recently, however, there has been a trend to use of Nephlometric Turbidity Units (NTU) or simply turbidity units (TU). For public water supplies, turbidity is limited

to five turbidity units (National Interim Primary Drinking Water Standards, 1977) natural groundwaters rarely have turbidity but if well construction and development is not proper, sediment can be produced with the pumped water creating turbidity.

Temperature

Temperature of water is important because many chemical and biological processes are temperature dependent. Groundwaters generally are cool and have little seasonal fluctuation in temperature. For most uses of water, temperature is not a critical parameter, however, for surface water systems, temperature becomes a very important parameter because of the direct relationship of aquatic life processes to water temperature.

Organic Compounds

Organic compounds can influence the quality of water and render it harmful or unusable for specific purposes. Pesticides, detergents, and municipal and industrial wastes are examples of organic compounds that can enter groundwater systems, and cause groundwater pollution. Organic compounds can cause tastes, odors, and can be toxic. Most groundwaters have low concentrations of organics and analyses for specific organics in water is expensive, time consuming, and is seldom done. The overall impact of organic materials on groundwater quality is not well known due to the analytical effort needed, however, it is thought that most groundwaters are relatively free of organic matter.

Gases

Common gases found in natural waters include oxygen, nitrogen, carbon dioxide, hydrogen sulfide, methane, ammonia, and oxides of nitrogen, and sulfur. Some of these gases are derived from the atmosphere, others may come from decaying organic matter or from industrial pollution. Common

gases found in groundwater are carbon dioxide, hydrogen sulfide, and methane. These gases can be corrosive and can cause problems when they come out of solution.

Saline Water

Some natural waters and many groundwaters in Montana contain dissolved materials concentrations exceeding 1,000 mg/l. Such waters have been classified by the U.S. Geological Survey as follows:

Concentration of Dissolved Solids (mg/l)	Description
1,000 to 3,000	Slightly saline
3,000 to 10,000	Moderately saline
10,000 to 35,000	Very saline
more than 35,000	Brine

The slightly saline type waters are commonly used in Montana and are suitable for some drinking water, agricultural, and irrigation uses. Moderately saline waters have much less use, but under some conditions, can be treated to produce water suitable for many uses. The very saline and brine waters are produced with oil in some portions of Montana, and are associated with some saline seep waters in Montana.

Micro-organisms

Micro-organisms in water commonly are a measure of its biological purity and freedom from pathogenic organisms. The presence of coliform organisms in water samples has been used as an indicator of biological purity for many years. More commonly, fecal coliforms are being used to indicate recent and possible dangerous pollution from sewage of fecal wastes. Generally, the earth is an excellent filter particularly porous media such as sands and silts. Fractured rocks and cavernous limestones

commonly do not provide good filtration and can transport micro-organisms long distances. It has been shown that micro-organisms can be transported several hundreds of feet in porous materials and for great distances in fractured materials. Generally, however, groundwater is a very hostile medium for the growth of micro-organisms. It is dark, devoid of oxygen, has a low temperature and substantial mechanical filtration occurs.
For public water supplies, the Interim Primary Drinking Water Standards require that the mean of monthly samples contain not more than one coliform bacteria per 100 milliliters of water.

Metals

In recent years there has been increasing concern about selected trace elements and toxic metals in waters. Of particular concern are elements such as aluminum, arsenic, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, uranium, vanadium, and zinc. Table 1 summarizes those criteria for the various water uses relative to these elements.

WATER QUALITY DATA PROCESSING SYSTEM

The Montana Water Quality Records System (MTWQRS) is a computer-based system for entering, maintaining, and retrieving records of water quality information. The system was designed by the Water Quality Bureau (WQB) and the Montana Bureau of Mines and Geology (MBMG), and developed in cooperation with the Montana Department of Community Affairs (DCA) under a contract to the U.S. Geological Survey and the Water Quality Bureau. In the past few years, large volumes of water quality data have been collected in Montana, with approximately 10,000 to 12,000 water quality samples collected each year. Laboratories are finding themselves more and more in need of rapid and accurate methods for processing large amounts of data. Data handling has become a new dimension in laboratory programs, and the analytical laboratory must now be concerned not only with generation, but with processing large amounts of data. Data users are concerned with storage retrieval and manipulation of the data.

The Water Quality Bureau and the Montana Bureau of Mines and Geology use essentially the same computer format for submittal to computer processing. The MTWQRS, still in the development stage, is capable of handling data from these two agencies. To date, the U.S. Geological Survey water quality data that has not been processed by the WQB or MBMG is available only through the STORET system or through the USGS computer system in Reston, Virginia.

The WQB, USGS, and MBMG contribute about 75 percent of the water quality data collected in the state. Supposedly, data in the USGS groundwater file in Reston, is not included in the MTWQRS. There is, however, no positive way of checking this without hand checking an enormous amount of data. The MTWQRS converts the various formats (several older data formats) of computerized water quality data, to a standard format. It then edits the data, converting raw lab data into more usable forms, such as calculating total dissolved solids, sodium adsorption ratios, and concentrations of certain ions from titration data. A master file stores the reformatted data, accessible for report writing. A number of report formats are possible including tabular outputs of Water Quality Bureau and MBMG water quality data which are in Appendix IV. This data is tabulated by county and by township-range-section within each county for easy cross referencing.

The master file is updated periodically with data records created and verified by the Water Quality Bureau and Montana Bureau of Mines and Geology. This information is also sent to the STORET system maintained by EPA in Denver. Computer mapping is also available through the MTWQRS.

There is an available backlog of water quality data in Montana in a computer adaptable format. Most, if not all, the USGS records have been entered into their own data handling system and into the national STORET system. That data entered in STORET is being edited by the MTWQRS, and will be available through the system. The groundwater data stored in the Reston, Virginia system is available to the MTWQRS on a computer tape file supplied by WESTECH. To create a master MTWQRS, these data should be entered into the system along with the WQB and MBMG data. There is also considerable data that are not in a format that can be easily entered into a computerized

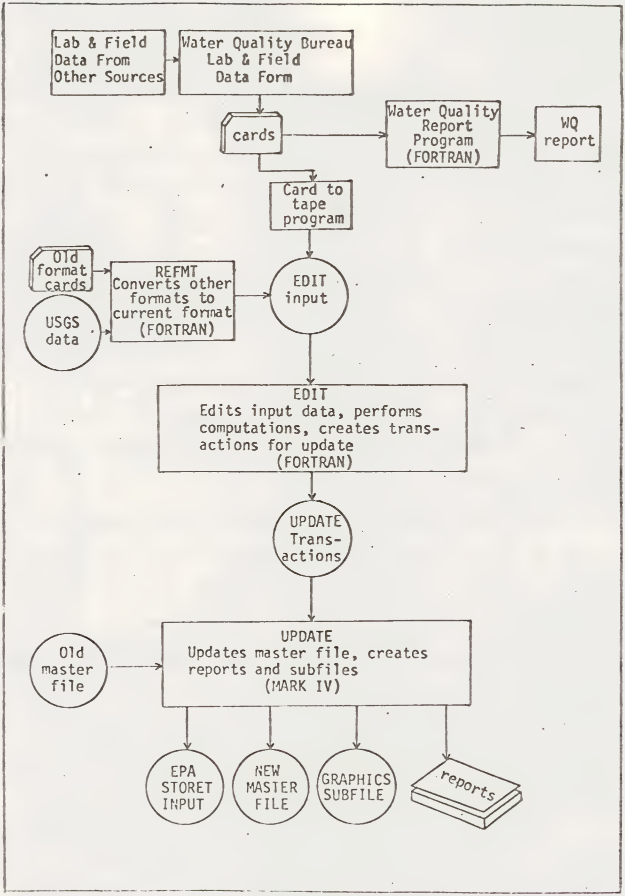


FIGURE 6. DATA PROCESSING SYSTEM

data system. This includes old data from various organizations and agencies in Montana and from organizations and groups that do not handle data by computerized systems. The quality, usefulness, and availability of these data would have to be determined.

Groundwater quality data is difficult and expensive to collect. If any information gathered has sufficient quality control, it should be entered into a common data processing system. This is the only cost-effective method of monitoring an area as large and geologically diversified as Montana. Incentives should be made to convince private laboratories, universities and government agencies to centralize their pool of groundwater data in the MTWQRS. While still developing, this is the most advanced system available that is adapated to Montana. Periodic review of the system by Montana users should increase its capabilities.

Included in Appendix IV are tabulations of the majority of groundwater quality data available in Montana. Besides the Water Qualtiy Bureau and MBMG data generated by the MTWQRS, a tabulation of USGS groundwater data was generated from their Reston, Virginia file. A tabular output of water quality data, published in USGS groundwater reports prior to 1967, is also included. This data was assembled on computer cards by Department of Natural Resources and Conservation in 1967. It is uncertain whether this data is also listed in the USGS output. Tabulated data from these four sources is nearly all of the Montana groundwater data available in computerized format.

Water Quality Data Sources

In Montana, there are a number of organizations and agencies that collect water qualtiy data. A list of all organizations in Montana that were thought to collect water quality data was prepared and persons in each organization were contacted to determine the amount of data generated.

The following summarizes information returned from the survey.

Water Quality Bureau

The Water Quality Bureau has statutory authority for investigation and control of water pollution in Montana. As part of their responsibilities, they collect substantial water quality data on streams, lakes, ponds, industrial and municipal discharges and have developed regulations that require communities, industries, and other discharges to self-monitor their wastes. The bureau laboratory runs approximately 3,000 samples per year with an average of about 13 parameters per sample. These samples are collected as part of technical investigations, intensive surveys, compliance monitoring, and water quality work for other organizations and agencies. There are approximately 1500 groundwater samples that have been processed to date in computer format.

Montana Bureau of Mines and Geology - Butte

The MBMG (Montana Bureau of Mines and Geology) is involved in a variety of research projects and technical investigations of water and water quality in Montana. They are analyzing approximately 3,500 samples per year. Many of these samples are associated with groundwater investigations and other samples include a variety of water types and some mining wastes. A large percentage of these groundwater samples are analyzed under contract to the USGS. Through 1975, the MBMG has processed approximately 1000 groundwater samples which will be entered into the MTWQRS.

U.S. Geological Survey

U.S. Geological Survey collects an estimated 1500 samples per year in Montana for chemical analysis. These include samples from wells, rivers, streams, and lakes and are associated with U.S. Geological Survey monitoring

programs. Some of these samples are analyzed by the MBMG. The remainder are sent to regional labs and are entered into the USGS national data processing center in Reston, Virginia. About 2000 data sets exists in this file and appear to be separate from those in the MTWQRS.

Universities and Colleges

Universities and colleges in Montana, particularly Montana State University and the University of Montana have a number of student and faculty projects that involved collection and analysis of water samples. It is estimated that there are approximately 800 samples per year collected by universities and colleges in Montana, most of which are surface water.

Soil Conservation Service

The SCS collects data on sediments, stream flow, and temperature at various locations. They collect an estimated 250 water samples per year, very few of which are for groundwater quality.

Montana Department of State Lands

The Montana Department of State Lands collects water quality samples associated with mining and other land activities in Montana. They collect an estimated 100 samples per year. These samples are analyzed by the Water Quality Bureau.

Montana Department of Fish and Game

Montana Department of Fish and Game collects samples as part of their responsibilities and in cooperative program with the Water Quality Bureau. They collect an estimated 250 samples per year, mostly surface waters.

Private Organizations

There are a number of private organizations in Montana that collect water quality data associated with the operation of their facilities. Much of

this data is for internal use and control of their systems and is not related to external discharges to the environment. External discharges to the environment are sampled as part of their compliance self-monitoring requirements. There are an estimated 500 samples collected per year by corporations, industries, and other businesses in Montana. Groundwater sampling by this group is growing in response to mining and waste discharge permit requirements.

Private Individuals

Private citizens in Montana submit samples to various laboratories, including the Water Quality Bureau for analysis for drinking water, stock, irrigation, and other purposes. It is estimated that approximately 500 samples per year are submitted for water analysis in Montana.

NATURAL GROUNDWATER QUALITY AND ASSOCIATED PROBLEMS

Groundwater in Montana shows a wide variation in quality reflecting large differences in climate, topography, and geology within the Statewide 208 Area. There are numerous natural groundwater problems that restrict the use of groundwater in many areas for irrigation, drinking water, and stock-water. To assess the overall quality of groundwater in Montana, eight computer-generated groundwater quality maps, developed as part of this investigation, were used to obtain an understanding of groundwater quality variations within the Statewide 208 Area. A number of additional sources were reviewed including U.S. Geological Survey publications, and data from municipal water supplies on file with the Montana Water Quality Bureau.

Generally, groundwater quality is good to excellent in the mountainous areas of Montana, and poor in the eastern and northern portion of Montana where geological formations are predominantly sedimentary and precipitation and runoff are substantially less. Natural groundwater quality problems include; problems with total dissolved solids, sulfate, iron, fluoride, nitrogen, and some trace substances such as boron, selenium, and lead. In most areas, groundwater tends to be slightly to substantially poorer in quality than surface water. This probably is due to the more intimate contact and longer period of time that groundwater has had to interact with earth materials. Deeper bedrock aquifers tend to be of poorer quality and the very deep aquifers encountered by oil and gas developments are some of the poorest quality groundwaters in Montana. The best quality groundwaters generally are in western Montana and are associated with shallow aquifers that receive substantial annual recharge.

Although groundwaters in the western portion of Montana tend to be of much better quality than those in eastern Montana, there are still problems of excessive hardness in many western waters and occasionally waters are high in total dissolved solids, sulfate, or other constituents. Generally, however, groundwaters in eastern Montana are the poorest in the state, and the majority of these groundwater supplies do not meet recommended water quality criteria for community water systems as defined by the National Interim Primary Drinking Water Standards or the U.S. Public Health Service (1962). This is not say, however, that these waters are not successfully used. In the absence of a higher quality water supply, these waters have proven to be adequate and they have been successfully used for many years. The dominant problems are high total dissolved solids, high sulfate, and high sodium, which makes the waters less desirable than higher quality waters in western Montana. Appendix II shows municipalities whose water supplies fail to meet National Interim Primary Drinking Water Standards because of high concentrations of one or more parameters.

In western Montana, groundwaters from unconsolidated shallow aquifers are usually of good quality but are hard. In central and eastern Montana, waters from unconsolidated aquifers typically are hard and range in quality from good to unusable. Glacial till in northcentral and northeastern Montana generally contains abundant soluble salts and groundwaters in these tills are of poor quality. Some shallow aquifers including some outwash and glacial deposits and the Flaxville Formation of Tertiary Age in northeastern Montana, have groundwater of fair to good quality. These deposits, however, are local in size, and are not major groundwater sources in eastern Montana.

Important sources of groundwater in eastern Montana are bedrock aquifers including the Fox Hills Sandstone, Hell Creek Formation, Fort Union Formation, Eagle Sandstone, Judith River Formation, the Kootenai Formation, Madison Limestone, and numerous other bedrock formations. Generally, these aquifers have fair to poor quality water and normally the water quality becomes poorer as the distance from the formation outcrop increases. Most water from bedrock formations are high in total dissolved solids and sulfate, but are suitable for nearly all uses including drinking water, stock and irrigation. The Fort Union Formation is widely exposed in eastern Montana and has water quality that varies from fair to very poor. The dominant nature of groundwater in bedrock formations in eastern Montana is variability with some trend to becoming poor to the east and northeast, and tending to sodium-sulfate type waters in the eastern portion of the state.

An assessment of water quality data from municipal water supplies in the Statewide 208 Area is shown in Appendix II. There are 110 water supplies that use groundwater exclusively; 33 that use surface water and 14 that use a combination of groundwater and surface water. Of the 110 groundwater-supplied communities, 49 (45 percent) do not meet recommended standards for total dissolved solids; 36 (32 percent) have more than the recommended sulfate concentration; 18 (16 percent) more iron than recommended; 4 (4 percent) more than recommended fluoride; and 5 (5 percent) more than recommended nitrite.

Nearly all towns that have water quality that exceeds recommended or mandatory standards are located in central, northeastern, or eastern, Montana.

These communities probably reflect the general trend in groundwater quality in the Statewide 208 Area.

Examination of the computer-generated maps shows statewide trends in seven water quality parameters that are of importance in various water uses including water supply, irrigation and livestock.

Groundwater Quality Maps

To obtain a better understanding of groundwater quality in Montana, seven computer-generated maps (Plates 1 to 7) were plotted to graphically show locations sampled and ranges of concentrations for seven parameters. These parameters are:

Specific Electrical Conductivity	Nitrate (NO_3) + Nitrite (NO_2)
Hardness	Iron
Sodium Adsorption Ratio	Zinc
Sulfate	

In addition to these seven parameters, one map (Plate 8) indicates if <u>any</u> of the following ten metals had been analyzed. These metals are:

Aluminum	Manganese
Cadmium	Mercury
Copper	Molybdenum
Iron	Selenium
Lead	Zinc

The map of metals indicates location only, and does not indicate a concentration range for these metals.

These water quality parameters were chosen because they are considered to be of significant interest for most water uses and there are substantial data available in the MTWQRS to be of value in assessing areal trends in groundwater quality. There are many other parameters that would be of value in determining trends in groundwater quality including fluoride, boron, orthophosphate, and a number of specific metals such as manganese, iron, molybdenum, and selenium. Due to the expense and limited scope of this project, these addtional maps were not developed but the computerized data

base is available and additional maps can be developed as funding is available. Computer generation of Plates 1 through 8 was a major task in this groundwater project, and, as described in the previous section, involved gathering of all available groundwater data; processing and storage of these data, and generation of a map file. Maps produced from this data file as part of this project, are the first groundwater quality maps ever produced from a statewide goundwater quality data file. The procedures, methodology, and usefullness of the MTWQRS has been demonstrated, and additional use of this file would be a relatively routine task. This file can be used to provide a variety of computer-generated maps with variable parameters, concentrations, symbols, and scales, at a cost of 1 to 2 cents per plotted point. Parameters selected for plotting are listed in Table 2, with appropriate units, symbols used, ranges selected, and plate numbers.

Generally, parameter limits were chosen for plotting to (1) show concentrations below which there seemed to be no environmental impact, (2) concentrations at which some adverse environmental impact could occur, but the water is suitable for most uses, (3) an upper limit that would severely restrict water use in nearly all cases.

Parameters selected for the plotting, and the rationale for limits, are described as follows:

Specific Electrical Conductivity

Specific electrical conductivity (SC) of groundwater was chosen due to its good relationship to total dissolved solids, ready availability of data and good correlation with total milliequivalents of major ions present in the water. The lower limit of 750 umhos (micromhos) was chosen because it is the upper limit of the medium salinity hazard for irrigation waters

TABLE 2.

SELECTED WATER QUALITY PARAMETERS

Parameter	Unit	Ranges	Symbol/Plate	No.
Specific Electrical Conductivity (SC)	umhos/cm	0-750 750-2250 >2250	+ □ x	1
Hardness	mg/l as $CaCO_3$	0-60 60-180 >100	+ □ x	2
Sodium Adsorption Ratio (SAR)	unit less	0-4 4-9 >9	+ □ x	3
Sulfate (SO_4)	mg/l	0-250 250-500 >500	+ x	4
Nitrate plus Nitrite ($NO_3 + NO_2$)	mg/l as N	0-0.35 0.35-10 >10	+ x	5
Iron (Fe)	mg/l	0-0.3 0.3-5 >5	+ x	6
Zinc (Zn)	mg/l	0-0.01 0.01-5.00 >5.00	+ □ x	7

(USDA, 1969), and also is approximately equivalent to a total dissolved solids concentration of 500 mg/l, which is a recommended upper limit for public water supplies (USPHS, 1962). The upper limit of 2250 umohs was chosen because it represents the upper limit that would normally be considered for a water supply. The range between 750 and 2250 umohs can be used for some irrigation purposes and in most domestic and municipal drinking water. A total of 2693 points were plotted from the data file.

Hardness

Limits selected for hardness plotting on Plate 2 are the same as hardness criteria suggested by the U.S. Geological Survey (Hem, 1970). The lower limit of 60 mg/l of hardness as $CaCO_3$ includes soft waters; 61 to 180 includes moderately hard, to hard waters and, hardnesses in excess of 180, includes waters that are very hard to extremely hard. A total of 2207 data points were plotted from the groundwater quality data file.

Sodium Adsorption Ratio (SAR)

This sodium adsorption ratio predicts reasonably well the degree to which irrigation waters can be used for crops. Limits chosen for plotting SAR on Plate 3 reflect the relationship of salinity hazard and SAR in irrigation waters. Suitability for irrigation water is not only dependent upon SAR, but is also dependent upon salinity hazard as measured by conductivity (USDA,1969). At an SAR of 4 (the lower limit chosen for plotting), SAR does not represent a constraint to use of irrigation waters until the waters have a very high salinity hazard. Similarly, the range of SAR of 4-9 (limits plotted on Plate 3), is a range where there is a medium SAR hazard when using irrigation

waters with salinity ranges between 250 and 2250 umhos (Figure 5). At SAR's in excess of 9, SAR in itself becomes a constraint to irrigation water use, and generally prevents use of such waters for many crops. A total of 1990 SAR values were plotted on Plate 3 from the groundwater data file.

Sulfate (SO_4)

The lower limit selected for plotting of sulfate is based on the U.S. Public Health Service recommended maximum concentration of 250 mg/l for public water supplies (USPHS, 1962). The intermediate range plotted extended from 250 mg/l to 500 mg/l. This range was selected since 500 mg/l SO_4 can have adverse impacts on livestock (McKee and Wolf, 1963). Waters in excess of 500 mg/l generally would be unsuitable for most uses and would be uncommon except in saline seeps, acid mine drainage, in some shallow aquifers in Montana, or in some deep brackish water aquifers. Plate 4 shows 2618 points where sulfate values were plotted.

Nitrate NO_3 and Nitrite NO_2

Nitrate plus nitrite is commonly measured on many waters in Montana. These nitrogen compounds are macronutrients and are present in nearly all groundwaters. The lower limit used for mapping on Plate 5 was 0.35 mg/l which is considered to be fairly indicative of natural groundwaters and waters with this concentration of nitrate plus nitrite generally do not lead to eutrophication of waters (A. Horpestad, Water Quality Bureau, pers. comm., 1978). Waters containing an excess of 10 mg/l of nitrate plus nitrite (as nitrogen) are not allowed for public water supplies (National Interim Primary Drinking Water Standards, 1977). Groundwater with a range of nitrate plus nitrite of 0.35 to 10 mg/l could have adverse impacts for some water uses, but generally would be suitable for most water uses. A total of 2606 samples were plotted on Plate 5 from the groundwater data file.

Iron (Fe)

The lower limit selected for iron is 0.3 mg/l which is the maximum iron concentration recommended for public water supplies (USPHS, 1962). Iron in excess of 0.3 mg/l causes staining and taste problems. Iron in excess of 5 mg/l can cause adverse affects in waters used for irrigation (EPA, 1972). Iron concentrations between 0.3 and 5 mg/l would be suitable for some uses. A total of 2418 values for iron were plotted on Plate 5.

Zinc (Zn)

A lower limit for zinc of 0.01 mg/l was used since zinc concentrations less than this amount are not known to have any adverse environmental impacts and groundwaters in their natural condition, normally have zinc concentrations less than 0.01 mg/l. The upper range of zinc concentrations chosen for plotting on these maps is 5 mg/l which is the recommended maximum limit for zinc allowable in public water supplies (USPHS, 1962). Zinc concentrations between these limits would need to be used with care and would be dependent on uses. A total of 341 groundwater samples with zinc concentrations were available from the MTWQRS and were plotted on Plate 6.

Selected Metals

In addition to the seven previously described parameters the ten metals were plotted on Plate 8. A data point on Plate 8 indicates that one of the ten metals were present, but does not indicate the concentration. The metals were chosen because they are commonly tested in water samples and indicate water suitability for many uses such as agriculture, drinking water, aquatic life, or other purposes.

Graphing Method

The computer-generated maps were plotted on a scale of 1 : 1,000,000 using the Lambert Conformal Projection which is the same base used for USGS maps.

This scale was chosen due to availability of base maps showing streams, drainage basins, township, range, and specific localities. The scale is large enough to give an overall statewide understanding of groundwater quality, yet small enough to be easily handled and used.

Computer generation of these maps was accomplished utilizing an IBM 370-145 computer with a drum plotter. Data sources for the mapped water quality data are the Montana Water Quality Bureau, Department of Health and Environmental Sciences, the Montana Bureau of Mines and Geology, and the U.S. Geological Survey (see previous section). About 3,000 sample records were available in computerized format and were used in development of these maps.

Three copies of each plate were printed - a clear mylar, a semi-transparency paper copy, and a blue-line paper print. Clear mylar is excellent for reproduction purposes, allows multiple overlay capabilities, and is very durable but expensive. The semi-transparent copy is useful for limited overlay work, can be used to make reproductions, and is fairly inexpensive. It is not as durable as mylar, however, and if damaged, reproduction quality is reduced. The paper copies are very inexpensive, are useful as work copies, and can be reproduced either from mylar or semi-transparent originals.

Natural Groundwater Quality

The computer-generated maps illustrate the variations in quality of natural groundwater in Montana.

A total of 2693 points were plotted on Plate 1 and 951 (35 percent) had a specific conductivity less than 750 umhos; 982 (36 percent) had a conductivity between 750 and 2250, and 760 (28 percent) had a conductivity in excess of 2250 umhos. Water less than 750 umhos is suitable for most uses, whereas waters greater than 2250 umhos have limited use even for irrigation. Waters in western Montana generally have specific conductances less than 750 umhos except for scattered points and an area along the Beaverhead River and near Townsend and Helena. In the central and eastern portion of the Statewide 208 Area, many waters had conductances between 750 and 2250 mg/l with some areas, particularly the extreme northern and eastern portions of the Statewide 208 Area, having nearly all conductances above 750 mg/l and many of them above 2250 mg/l.

Water in the western portion of the Statewide 208 Area generally has hardness of 60 to 180 mg/l with many waters having hardness in excess of 180 mg/l, particularly in the southwest. The remainder of the Statewide 208 Area generally has waters that range in hardness from 60 to 180 mg/l with a few scattered areas of soft water including the northern part of Choteau County, and an area in eastern Montana in southern Prairie County. In eastern Montana, many waters exceeded 180 mg/l of hardness. As described previously in this report, extreme hardness in water causes problems with incrustations and in household use. Of the 2207 points plotted for hardness (Plate 2) in Montana, 410 (19 percent) had hardness less than 60; 501 samples (23 percent) had hardnesses between 60 and 180, and 1296 points (59 percent) had hardnesses greater than 180 mg/l.

A total of 1990 points were plotted for SAR (Sodium Adsorption Ratio) on Plate 3. Of these, 1222 (61 percent) had SAR's less than four; 267 (13 percent) had SAR's from four to nine, and 501 points (25 percent) had SAR's greater than nine. In the western portion of the Statewide 208 Area, nearly all waters had an SAR less than four. In the northern and northcentral portion of the 208 Area, in Toole, Liberty, and portions of Cascade County, and some locations in nearby counties, SAR's ranged from four to greatern than nine, with many localities being greater than nine. In the eastern part of the Statewide 208 Area, SAR is somewhat variable, but tends to be between four and nine, with some greater than nine. Many locations in McCone, Dawson, and Richland Counties have SAR's greater than nine. An SAR greater than nine generally inhibits use of water for most irrigation. Waters less than four, however, are suitable for most irrigation uses (see Section VII).

Sulfate is a major anion in groundwater systems in Montana and is particularly abundant in northern and eastern Montana. A total of 2618 groundwater analyses were plotted (Plate 4) with 1636 of these (62 percent) containing less than 250 mg/l sulfate which make these suitable for most water uses. A total of 227 points (9 percent) were between 250 and 500 mg/l sulfate, and 755 points (29 percent) were greater than 500 mg/l of SO_4. In western Montana nearly all sulfate samples were less than 250 mg/l with an occasional groundwater sample between 250 and 500 mg/l. In the northcentral portion of the 208 Area, most groundwater samples were less than 250 mg/l but there were increasingly more samples between 250 and 500 mg/l and some exceeded 500 mg/l. In the eastern and northeastern portions of the Statewide

208 Area, groundwater is distinctly poorer in quality with many areas having an excess of 250 mg/l sulfate and some exceeding 500 mg/l.

Nitrogen less than .35 mg/l generally does not create undesirable water quality conditions. When nitrate plus nitrite exceeds 10 mg/l, it is no longer suitable for use as a public water supply. A total of 2606 points were plotted for Montana, and are shown on Plate 5. A total of 980 points (38 percent) had $NO_3 + NO_2$ less than .35 mg/l as nitrogen; 1439 (55 percent) had $NO_3 + NO_2$ between .35 and 10 mg/l, and 187 (7 percent) had $NO_3 + NO_2$ greater than 10 mg/l. In the Statewide 208 Area there are only scattered points with nitrates in excess of 10 mg/l.

A total of 2418 points were plotted on Plate 6. Iron less than 0.3 mg/l is suitable for nearly all uses including municipal water supplies. In excess of 5 mg/l iron becomes inhibiting to many uses of water.

A total of 1926 points (80 percent) had iron values less than 0.3 mg/l; 346 (14 percent) 0.3 to 5 mg/l, and 146 (6 percent) in excess of 5 mg/l. In the Statewide 208 Area nearly all the iron concentrations were less than 0.3 mg/l except for a number of scattered localities where iron was between 0.3 and 5 mg/l. Almost all the points in excess of 5 mg/l were either at the Cooke City or Hughesville acid mine drainage study sites. There were also high irons in portions of Cascade, Judith Basin, Broadwater, Glacier, and Blaine Counties, and in a few counties at the northeastern portion of the Statewide 208 Area.

Zinc can be important in aquatic systems at concentrations greater than .01 mg/l, and it is recommended that public water supplies contain less than 5 mg/l zinc. On Plate 7 a total of 341 points were plotted including 94 points (28 percent) that were less than .01 mg/l; 188 points between .01 and 5.0 mg/l (55 percent), and 59 (17 percent) were greater than 5 mg/l. Many of the samples were groundwaters from acid mine drainages in the Cooke City area in Park County and in the Hughesville area in Judith Basin County. There were insufficient zinc determinations in groundwaters in the remainder of the state to determine any areal trends, however, many groundwaters have greater than .01 mg/l zinc.

Boron was not plotted as a specific parameter, however, a review of U.S. Geological Survey, Water Quality Bureau, and Montana Bureau of Mines and Geology data for Montana shows that boron is nearly always less than 0.75 mg/l. In some selected parts of Montana, particularly in the Poplar River drainage in Daniels and Roosevelt Counties, boron sometimes exceeds .75 mg/l. Other areas of the state include Broadwater Hot Springs in Helena, Montana and a few scattered areas in McCone and Musselshell County.

GROUNDWATER USE IN MONTANA

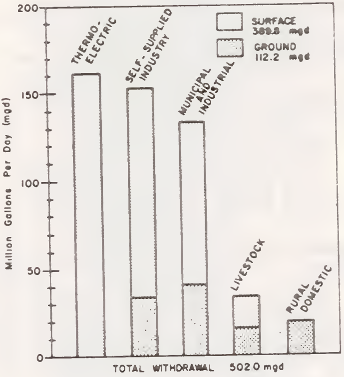
The widespread availability of groundwater and its desirable properties, such as clarity, bacterial purity, and generally consistent temperature and chemical quality, have led to widespread use of groundwater systems. In 1970 about two percent of the water used in Montana was groundwater (EPA, 1975), which is much less than most western states. Although this is a small percentage, it represents a vital resource that can and will be further developed as surface water supplies become limited.

Management and protection of groundwater resources is important. Whereas pollution of surface water is readily detected and often can be readily corrected, pollution of groundwater is often not detected until a considerable part of an aquifer has been affected. A great deal of time may be required for an aquifer to remove or reduce the influence of pollution and commonly a large effort is needed to correct aquifer pollution problems.

Major uses of groundwater in Montana are irrigation, municipal, industrial, rural, domestic, and livestock. As described by Ricks (1975) rural domestic water requirements are supplied almost totally by groundwater, using 19.6 mgd (million gallons per day), and serves 197,000 persons. An additional 16.8 mgd of groundwater is used for watering livestock (Figure 7).

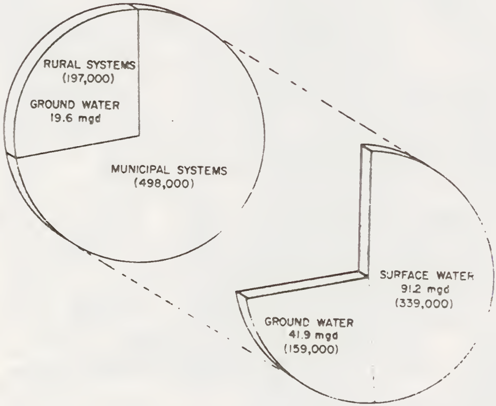
Municipal systems obtain about 31 percent of their water supply, or 41.9 mgd from groundwater, and serve 159,000 persons (Figure 8). It should be noted that the new Clean Drinking Water Act (Public Law 93-523) defines public water supplies as any supply that furnishes 10 residential units or 25 or more persons. This will increase the number of public supplies in Montana from 221 to an estimated 1,000 to 1,500. All the quantities shown are for the entire state. The Statewide 208 Area contains about 65 percent of Montana population, or 486,750 persons (DCA, 1977). Based on a 65 percent share of groundwater

WITHDRAWALS BY SOURCE
(USES OTHER THAN IRRIGATION)



	GROUND (mgd)	SURFACE (mgd)	TOTAL WITHDRAWAL (mgd)
THERMOELECTRIC	0.0	163.0	163.0
SELF-SUPPLIED INDUSTRY	33.9	118.8	152.7
MUNICIPAL AND INDUSTRIAL	41.9	91.2	133.1
LIVESTOCK	16.8	16.8	33.6
RURAL DOMESTIC	19.6	0.0	19.6

Figure 7. Groundwater use in Montana (Ricks, 1975)



	POPULATION SERVED		WITHDRAWAL (mgd)	
MUNICIPAL SYSTEMS		498,000		133.1
SURFACE WATER	339,000		91.2	
GROUND WATER	159,000		41.9	
RURAL SYSTEMS		197,000		19.6
TOTAL		695,000		152.7

Figure 8. Population Served by Source (Ricks, 1975)

useage, about 231,400 persons or 48 percent of the entire Statewide 208 Area is served by groundwater. Self-supplied industrial water accounts for a total of 152.7 mgd, of which 33.9 mgd is groundwater. Thermoelectric cooling water is supplied almost entirely by surface waters and accounts for most of the water used by industry.

Groundwater also in used in oil production. Major water flooding systems in the Statewide 208 Area include oil fields near Cut Bank, Havre, and Roundup. In 1976, about two mgd were pumped, mostly from the Madison, for secondary recovery near Cut Bank (Oil and Gas Cons. Div., 1977). The Havre and Roundup areas use about 0.5 mgd each. Minor water flooding systems are operated near Sunburst, Sidney, Plentywood, Poplar, Culbertson, and Glendive. Together, these withdraw about 600,000 gpd. The 3.6 mgd used by the oil industry does not include water produced with the oil, but is drawn from other aquifers in order to increase pressures in a producing oil zone.

Outside the Statewide 208 Area are several oil fields that, combined, use close to 6 mgd (Oil and Gas Con. Div., 1977). Therefore, the oil industry uses nearly a third of the industrial self-supplied groundwater.

Total water use for irrigation amounts to 12.4 million acre-feet of water (22,165 mgd) over a six-month irrigation season each year. Surface sources yield 99 percent of this water, while one percent (222 mgd) is groundwater (Ricks, 1975). Thus, an equivalent of 111 mgd groundwater is withdrawn over an entire 12-month period, about equal to the entire amount supplied for all other groundwater uses in Montana. A minor amount of hot water from thermal wells and springs in used in Montana for heating with a rapidly growing interest in this activity.

Trends in Use

There has been a relatively constant rate of groundwater development for rural domestic and livestock water supplies (Table 3). In many areas, groundwater is the only reliable source available for development. It is likely that this trend will continue as more rangeland is developed and improved, and more people move to areas not served by municipal systems. The rapid rate of development of subdivisions should also increase groundwater use.

Use of groundwater for irrigation will undoubtedly increase substantially. In recent years, a number of irrigation systems using groundwater have been installed. Surface water supplies are over-appropriated in many areas, and more systems will depend upon groundwater for crops. This use of groundwater depends heavily on assurance of a constant supply of suitable high quality water. This will be a major impact on groundwater supplies in the future.

As primary production of oil from old wells decreases, a greater amount of groundwater will be used for secondary and tertiary recovery. Oil companies have the capability to use deep groundwater aquifers, and there will be an increasing dependance on groundwater for this purpose. Secondary recovery units range in size from several injecting wells to nearly a hundred, and are supplied by water withdrawn from an area usually within the boundaries of the oil well field itself (Oil and Gas Conservation Division, 1977).

Potential new uses for groundwater may include solution mining and slurry pipelines. These activities presently do not occur in Montana, but are technically proven in other areas of the United States. Solution mining would involve use of several hundred gallons of water per day used as makeup water to replenish a recycle system. Only two areas of Montana are being seriously considered for uranium solution mining, both outside the Statewide 208 Area.

Table 3. Number of well forms filed each year

Source: Montana Bureau of Mines and Geology - Groundwater Branch

NUMBER OF WELL FORMS FILED EACH YEAR MONTANA BUREAU OF MINES AND GEOLOGY GROUNDWATER BRANCH 11 71

County	Thru 1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954
Beaverhead	286	6	[illegible]	8	5	21	12	11	19	-	20	21	23	25	17
Big Horn	159	2	12	8	5	20	14	8	15	10	29	8	10	13	21
Blaine	153	3	[illegible]	8	4	10	5	29	31	20	8	6	10	12	[illegible]
Broadwater	157	[illegible]	[illegible]	1	4	4	10	7	10	5	18	2	6	5	12
Carbon	21	3	[illegible]	0	1	1	1	1	3	4	3	1	4	3	9
Carter	172	2	[illegible]	12	7	14	21	8	9	17	17	9	15	14	15
Cascade	505	6	11	11	12	12	14	14	29	26	44	29	34	41	27
Chouteau	392	7	9	7	14	14	25	14	20	26	20	16	11	11	15
Custer	353	20	12	15	17	25	39	25	24	12	31	18	14	19	11
Daniels	227	8	11	6	8	20	8	10	15	3	4	13	11	15	6
Dawson	325	14	14	21	10	27	19	20	20	23	35	20	34	30	20
Deer Lodge	138	12	9	8	4	5	10	3	7	3	19	12	12	23	15
Fallon	155	5	17	14	13	27	16	27	34	13	32	17	22	14	12
Fergus	433	6	5	5	13	14	13	21	42	29	39	28	14	25	8
Flathead	514	5	11	16	12	36	37	24	55	37	51	38	36	53	62
Gallatin	799	12	10	18	12	20	22	32	24	23	36	17	27	26	29
Garfield	217	3	15	10	13	30	38	28	65	31	45	33	37	20	14
Glacier	149	0	11	4	5	6	7	8	8	4	13	4	13	13	12
Golden Valley	123	0	2	2	0	11	8	6	12	10	13	2	4	7	6
Granite	124	1	3	2	2	6	3	7	9	5	9	3	7	4	5
Hill	286	[illegible]	14	9	-	16	19	10	19	9	14	14	17	21	21
Jefferson	185	3	2	5	3	4	8	2	-	2	4	5	6	7	5
Judith Basin	211	1	6	5	2	11	15	3	14	12	20	13	14	6	14
Lake	268	6	12	10	5	17	18	21	35	25	17	15	20	20	9
Lewis and Clark	361	1	8	9	5	20	16	9	25	25	23	17	23	30	17
Liberty	105	3	1	6	5	8	2	5	9	10	11	9	8	6	8
Lincoln	65	1	4	2	3	4	2	5	11	5	15	16	23	23	17
Madison	454	4	[illegible]	4	[illegible]	17	16	13	17	12	24	9	9	11	12
McCone	12	4	3	12	9	16	15	11	14	5	9	16	13	17	17
Meagher	65	0	2	1	0	0	2	4	1	1	3	-	4	1	0
Mineral	19	0	1	0	0	0	1	2	2	2	3	0	1	4	3
Missoula	244	9	26	18	8	20	27	19	38	30	36	28	20	31	49
Musselshell	211	5	6	7	16	17	22	31	38	21	44	30	28	34	27
Park	219	1	5	5	2	9	9	5	15	10	9	1	12	4	4
Petroleum	53	0	0	1	0	4	14	8	1	3	9	6	10	7	3
Phillips	357	13	17	18	16	26	32	31	32	26	39	20	40	27	24
Pondera	152	2	4	2	3	2	3	7	9	-	[illegible]	6	3	6	3
Powder River	638	22	29	24	23	50	56	60	61	47	53	47	52	49	59
Powell	153	3	2	1	1	3	7	-	10	5	11	-	14	12	2
Prairie	113	4	11	10	8	19	15	10	18	14	27	14	16	19	7
Ravalli	609	21	18	25	14	24	37	50	41	33	54	31	32	28	31
Richland	340	17	22	15	14	27	15	30	33	21	34	15	25	30	18
Roosevelt	204	-	15	6	4	7	8	10	17	14	15	26	15	9	15
Rosebud	194	5	4	9	6	15	48	32	29	12	30	14	13	12	32
Sanders	143	1	5	2	1	5	12	14	14	9	12	4	11	5	9
Sheridan	221	-	9	6	7	5	6	8	9	-	9	8	7	7	13
Silver Bow	118	1	3	3	2	3	1	3	3	2	-	9	5	4	11
Stillwater	156	3	21	16	6	8	16	15	17	16	17	12	13	7	9
Sweet Grass	191	3	3	1	5	6	6	15	14	-	11	2	10	7	6
Teton	477	16	25	12	12	14	17	19	45	17	32	22	32	30	13
Toole	126	5	3	5	3	12	9	3	[illegible]	2	-	2	4	5	5
Treasure	5	1	5	4	5	9	7	7	-	5	12	5	9	7	8
Valley	429	-	14	19	9	28	21	19	32	22	35	34	19	39	26
Wheatland	153	1	5	12	8	16	9	9	5	10	11	3	10	5	7
Wibaux	130	[illegible]	5	4	7	6	13	6	20	10	27	8	8	3	[illegible]
Yellowstone	417	14	19	15	25	26	49	45	38	26	45	31	35	33	36
Total	[illegible]	351	511	450	418	802	895	863	1,167	747	1,218	813	923	945	874

County	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Beaverhead	14	17	20	28	22	47	45	44	41	24	13	10	11	26	32
Big Horn	13	8	12	10	10	11	31	10	28	5	7	5	5	4	5
Blaine	10	10	16	12	17	11	46	29	36	24	9	7	3	2	4
Broadwater	8	12	11	9	20	13	11	22	31	7	8	3	11	11	14
Carbon	5	0	17	12	15	28	20	12	2	0	0	1	21	26	28
Carter	20	18	26	52	53	41	70	33	33	8	14	15	10	12	9
Cascade	36	31	26	31	57	53	61	49	65	14	5	15	16	24	29
Chouteau	25	13	16	13	15	33	28	35	24	10	6	1	1	3	6
Custer	32	23	27	38	36	34	33	15	13	16	5	5	8	2	1
Daniels	7	8	12	13	7	7	10	9	13	6	11	1	5	2	4
Dawson	34	45	31	59	60	77	63	27	53	27	10	18	17	23	14
Deer Lodge	18	24	43	60	33	39	22	14	16	6	6	9	6	6	5
Fallon	16	33	19	30	43	52	41	24	21	4	3	3	3	4	4
Fergus	9	16	46	40	26	49	96	37	39	20	14	18	15	11	11
Flathead	61	67	65	66	51	43	54	59	64	65	57	28	90	92	71
Gallatin	49	46	53	72	61	100	97	80	81	55	61	59	53	64	40
Garfield	24	35	25	59	43	33	99	26	40	20	5	8	6	11	6
Glacier	19	11	8	14	12	18	16	13	25	6	2	3	4	9	7
Golden Valley	5	8	18	15	20	13	41	10	9	2	7	3	3	5	3
Granite	5	7	13	5	9	7	8	9	19	17	7	7	10	16	13
Hill	26	26	32	30	43	25	56	34	28	26	6	4	6	21	1
Jefferson	5	5	6	9	5	7	20	9	12	5	4	6	9	16	22
Judith Basin	16	16	22	12	17	25	52	16	13	5	2	4	2	6	6
Lake	21	19	22	18	19	26	58	30	30	39	15	16	32	76	41
Lewis and Clark	33	14	51	48	49	56	57	61	68	33	43	38	28	63	49
Liberty	12	7	11	9	4	11	22	12	5	1	2	6	1	0	2
Lincoln	26	21	32	33	20	23	33	32	43	29	38	28	50	44	31
Madison	9	5	8	21	27	21	15	24	21	24	30	18	14	17	22
McCone	10	15	7	49	24	33	57	20	32	21	16	3	13	7	12
Meagher	5	4	4	10	6	5	8	12	4	0	2	1	0	4	3
Mineral	5	2	14	5	13	9	3	7	12	7	8	6	10	8	7
Missoula	47	34	60	63	57	59	67	83	81	92	70	61	62	91	66
Musselshell	31	36	46	59	26	50	83	16	18	9	29	28	13	18	1
Park	13	6	19	21	12	18	39	22	16	17	14	15	10	13	13
Petroleum	4	7	11	19	9	9	36	4	4	2	7	9	5	0	10
Phillips	14	11	40	72	40	29	45	27	14	16	14	14	16	11	6
Pondera	5	8	6	4	3	9	2	9	10	6	6	0	2	2	2
Powder River	51	55	55	74	76	90	104	33	50	28	26	24	18	16	19
Powell	11	15	11	9	14	18	23	7	11	5	3	2	12	6	6
Prairie	12	17	23	26	42	39	50	13	19	12	18	19	32	12	12
Ravalli	40	40	39	54	64	53	63	67	69	55	69	39	51	78	71
Richland	24	23	29	98	51	47	69	41	55	20	15	9	17	24	26
Roosevelt	13	23	22	30	18	16	45	32	18	12	5	6	5	8	7
Rosebud	43	51	32	46	36	61	43	33	40	23	3	8	8	4	4
Sanders	7	6	6	13	11	14	10	20	--	21	14	13	13	16	15
Sheridan	14	9	28	32	17	12	20	23	42	16	11	3	3	2	0
Silver Bow	11	4	13	9	8	13	14	8	20	6	6	8	8	17	11
Stillwater	15	13	17	25	37	39	62	27	42	22	10	24	13	11	27
Sweet Grass	[illegible]	7	4	14	6	8	19	11	8	4	6	4	3	0	9
Teton	14	30	22	27	23	30	36	27	26	8	4	1	2	6	5
Toole	1	16	13	15	8	10	22	7	15	4	2	2		2	1
Treasure	15	10	3	10	5	19	13	3	6	14	2	5	2	1	2
Valley	31	31	50	40	34	42	52	28	42	25	22	20	17	8	10
Wheatland	8	10	13	22	12	10	27	18	22	5	11	3	2	7	1
Wibaux	13	18	13	28	25	22	35	26	23	20	15	6	9	13	8
Yellowstone	41	42	56	79	96	50	78	46	51	22	39	39	17	18	20
Total	1,065	1,120	1,344	1,771	1,567	1,711	[illegible]	1,443	1,675	990	837	711	806	999	854

Potash deposits in northeastern Montana also have a good potential to be solution mined. With only a few operations being considered, it is not expected to involve a significant amount of groundwater usage.

Slurry of coal or other solid materials is receiving considerable attention. Slurry systems appear to be cost competitive with rail systems, but are restricted by political and legal controls. The operation of a coal slurry pipeline provides the capacity for moving about 25 to 40 million tons of coal per year, which requires 25 to 40 cfs of water (16 to 26 mgd). A middle range would be equivalent to about one-half the entire use of groundwater for municipal purposes, or about one-fifth that now used for irrigation. Assuming that adequate supplies can be found near the coal fields, one pipeline could increase groundwater usage in Montana by about 15 percent, and total water usage by about 0.2 percent.

Cooling water for power plants is supplied almost entirely by surface water. It is not expected that groundwater will be used to any significant extent for thermoelectric power generation. Feasibility studies have been conducted to decide whether geothermal conditions are suitable for power generation but have not been conclusive. It appears that such use of groundwater is not economically feasible now, but could be as fossil fuel prices continue to rise. If and when heat pump systems are competitive with conventional systems for space and hot water heating, the use of groundwater for heat storage has almost unlimited possibilities. Heat pumps are devices similar to air conditioners in reverse, taking heat out of outside air or water and transferring it into useable heat for buildings. This application would be available to rural, municipal, suburban, and industrial entities.

Distribution

The distribution of groundwater use is statewide. Rural systems, that is, small towns, individual households, and livestock supplies, use a significant proportion of the total groundwater supplied, or about 17 percent. As indicated by the term "rural", these users are everywhere. A great deal of rural usage, however, is concentrated in subdivisions near the larger cities and towns. Besides the concentration of numerous private wells, usually in shallow aquifers, the municipal water supply for an adjacent community can withdraw a significant amount of groundwater. This is one area where a balance among many pumping wells, limited recharge areas, and many sources of pollutants (sanitary, solid wastes, pesticides) becomes important.

Other uses, industrial and agricultural, generally withdraw water from one well or battery of wells, as do large cities. These systems create a significant local drawdown which can reduce the usefulness of the same aquifer for other uses. Ordinarily, large drawdowns are not likely to change the quality of a particular aquifer, but place a burden upon former users in terms of greater pumping costs or redrilling.

Compared to other western states, Montana has considerable groundwater resources, but currently is using much less of this resource to supply water needs. Future uses of groundwater are clearly going to increase, and provide a much greater share of the states future water demands (EPA, 1975).

REGULATORY FRAMEWORK

A number of federal and state agencies administer laws and regulations concerned with groundwater quality. An even greater number of agencies regulate groundwater quality in some general way. The Reclamation Division, Montana Department of State Lands, and the Water Quality Bureau, Montana Department of Health and Environmental Sciences, are the lead state agencies concerned with groundwater quality issues. The United States Bureau of Land Management, Geological Survey, Forest Service, and Environmental Protection Agency are the federal agencies that also have laws and rules that involve groundwater quality.

Federal and State Statutes and Regulations

Mineral Leasing Act of 1920

Under this Act, certain minerals are considered leasable, and not locatable, and are developed through prospecting and leases. An operator can only obtain from the federal government the right to explore and mine certain minerals, but can never acquire the surface in private ownership. As since amended, this act covers oil, gas, coal, oilshale, sodium, potassium, phosphate, native asphalt, solid or semi-solid bitumen, bituminous rock, and oil-impregnated rock or sand.

Regulations of the Secretary of the Interior for most minerals discussed in this Act are contained in 43CFR Group 3500 - Leasing of Minerals Other Than Oil and Gas. Regulation 43CFR Part 23 provides for protection of nonmineral resources during operations for discovery and development of minerals under permits and leases issued under the Act. A technical examination must be made of all proposed exploration or development areas. Based on this examination, special stipulations assuring protection of

nonmineral resources and the environment, including groundwater quality, are made part of the permit or lease. Where BLM does not administer the surface, the surface managing agency, such as the Forest Service, makes recommendations concerning these stipulations (USGS, 1977).

Materials Act of 1947

Salable minerals are petrified wood and common varieties of stone, sand, gravel, pumice, pumicite, cinders, and some clay. These materials may only be acquired by purchase from the federal land managing agency, either through competitive bid or negotiated sale. Other uses of the same land may take place if not interfering with the mining operation, and the mined land must be reclaimed.

Surface Mining Control and Reclamation Act of 1977 and Final Interim Regulations

The Surface Mining Control and Reclamation Act was signed into law on August 3, 1977 and establishes national standards for coal mining and reclamation. Of particular concern in the Act is the effect of mining on hydrologic systems. The Act requires that the Secretary of Interior publish initital regulations applicable to all coal mining operations regulated by the states until each state has an approved regulatory program or a federal regulatory program implemented in that state. These initial regulations took effect February 3, 1978 and will stay in effect throughout the initital program phase.

Major aspects of these regulations consider (1) general performance standards for surface and underground mines governing restoration of disturbed areas to suitable post-mining use, backfilling, protection of the hydrologic system, and construction, inspection, and maintenance of dams; (2) special performance standards governing steep slope mining, prime farmlands, and

mountain top removal; (3) procedures for adopting state laws where they are found to be more stringent than federal regulations; (4) regulations governing enforcement activities and inspections; and (5) financial and other assistance to eleigible small coal mine operators in determining the hydrologic consequences of mining and reclamation.

Given the small scale nature of coal production in the Statewide 208 Area, a detailed analysis of these comprehensive and complex regulations is not appropriate. Several sections of the regulations have direct and indirect implications on water quality. Together with existing state statute and regulation, they constitute a stringent and complete regulation of the coal mining industry.

Operators are required to restore the hydrologic balance of the system after cessation of mining. This requirement is the most stringent of any regulation governing any type of mining in the nation. The objective of this regulation is:

> to have the permittee research and understand the hydrologic balance in the affected area as well as to understand the effect of mining on that balance so that operations are planned and conducted to minimize disturbances both on and off-site. Since the hydrologic balance may be restored only after long periods of time, it is necessary for the permittee to project long-term trends toward restoring the balance (Office of Surface Mining, 1977 p.).

Specific aspects of these regulations regarding protection of groundwater systems include:

(1) Groundwater resources must be protected. Reclamation must ensure that the former recharge capacity of the mined area is re-established. Groundwater levels and quality must be monitored.

(2) Special provisions regulating coal mining in and near alluvial valley floors, which are defined as:

> unconsolidated stream-laid deposits holding streams where water availability is sufficient for subirrigation or flood irrigation agricultural activities but does not include upland areas which are generally overlain by a thin veneer of colluvial deposits composed chiefly of debris from sheet erosion, deposits by unconcentrated runoff or slope wash, together with talus, other mass movement accumulation and windblown deposits (710.5).

(3) Mining in and near alluvial valley floors:

> Shall be planned and conducted so as to preserve the essential hydrologic functions of these alluvial valley floors throughout the mining and reclamation process. These functions shall be preserved by maintaining or re-establishing those hydrologic and biologic characteristics of the alluvial valley floor that are necessary to support the functions. The characteristics of an alluvial valley floor to considered include, but are not limited to:
>
> (i) Aquifers and confining beds within the mined area which provide for storage, transmission, and regulation of natural groundwater and surface water that supply the alluvial valley floors;
>
> (ii) Quantity and quality of surface and groundwater valley floors;
>
> (ii) Depth to and seasonal fluctuations of groundwater beneath alluvial valley floors.

These regulations are a stringent control of mining near perennial and intermittent streams designated as alluvial valley floors. These regulations are new and it is not clear at this time how phrases such as "preserve and maintain" or "materially damage" will be interpreted. Whatever the case, coal strip mining will be more closely controlled by the Montana Reclamation Division and the Office of Surface Mining. The clear intent of the law and regulations is to preserve existing groundwater quality.

Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500)

In October, 1972 Congress amended the 1965 Federal Water Pollution Control Act. The amendments were designed to provide regulation and planning for improvement of water quality in the nation's waters. This law was designed to regulate discharges of pollutants from point sources. It also provided for administration of detailed regulatory rules at the state level. In response to this law, Montana passed regulations for control of point source waste discharges and developed detailed water quality standards. The basic thrust of P.L. 92-500 is to control point source discharges to surface water, but the law has had both positive and negative impacts on groundwater.

As part of the overall strategy for elimination of pollutant discharges to the nation's waters, the EPA is establishing guidelines spelling out the maximum amount of pollutants acceptable from any particular industry.

There are 21 categories that EPA considers to be the major contributors of industrial point source pollution. Technical studies aimed at characterizing these industries and their discharges are now being conducted by EPA. Concurrently, technologies available for control and treatment of the characteristic pollutants and the economic impacts of the various control options are being assessed.

There are three basic levels or degrees of pollution control. The first is the application by a discharger of the best practicable control technology currently available (BPCT). A particular BPCT is determined by the EPA as described above, and is supposed to be in force in all discharge permits issued after July 1, 1977. The second degree of control is called the best available technology economically achievable (BAT) and represents a higher quality of discharged waters. Since these regulations are usually

more stringent, more time has been allowed both for determining the BAT's and for their industrial application. The deadline of July 1, 1983 was the date set by P.L. 92-500, but is likely to be extended one year by a bill now before Congress (Montgomery, pers. comm., 1977, Chemical Engineering, December 5, 1977).

The third level deals with new sources of pollutant discharges. Usually in the design and construction of new plants or mining operations, a higher level of environmental control can be institued with relatively little increase in cost. In contrast, older operations need to be modified at a greater cost, plus the cost is generally not included in the original economic feasibility.

These specific BPT, BAT, and New Source Performance Standards all emphasize reduction in pollutants produced for given industrial processes. This reduces the overall environmental burden and probably has an overall positive benefit on all water systems including groundwater.

The Law (P.L. 92-500), however, controls surface disposal of wastes and makes ground disposal alternatives more advantageous. The overall impact probably increases groundwater pollution due to the less restrictive regulations on disposal into groundwater systems.

Montana Pesticides Act

Title 27, Chapter 2, Section 213-145, R.C.M. 1947

Damage to plants and loss of vegetation from chemical applications can result in soil erosion, debris, sedimentation, and other causes of water pollution. The federal government has enacted several measures to reduce water pollution from the intrusion of these chemicals into surface and groundwaters, and to reduce the destruction or damage to plant life which can result

from misuse of such chemicals. State law (enacted in 1971) provides for the administration of the Federal Insecticide, Fungicide, and Rodenticide Act. This function is implemented through the State Department of Agriculture and includes licensing of dealers and applicators of chemical treatments.

Oil and Gas Operating Regulations

Oil and gas operating regulations are under CFR 30, Part 221 and they relate to exploration, production and development of oil and gas in Montana. Specific sections of the regulation that relate to water pollution are:

Section 221.28 Requires the lessee to shut off and exclude all water from any oil or gas bearing structure to the satisfaction of the supervisor.

Section 221.32 This section states: "The lessee shall not pollute streams or damage the surface or pollute the underground water of the leased or other land. If useless liquid products of wells cannot be treated or destroyed, or if the volume of such products is too great for disposal by usual methods without damage, the supervisor must be consulted, and the useless liquids disposed of by some method approved by him."

Section 221.34 Well abandonment and plugging is specified in this section including requirements for the lessee to submit a detailed plan for carrying on the necessary work. No well can be abandoned only after receipt of written approval by the supervisor. If water is encountered while drilling instead of oil or gas, the well may be used as a water well in lieu of plugging and abandonment.

Penalties are provided in case of violations of regulations by lessee. Section 221.53 authorizes the supervisor to shut down any operation and place under seal any property or equipment for failure to comply with these regulations. Failure to file notice and to obtain approval before repairing

redrilling, deepening, plugging-back, plugging, or abandoning any well; in pulling or altering casing stimulating production by vacuum, acid or shot, or gas, air, or water injection, or using any well or formation for gas storage or water disposal, results in a $25 fine for each violation. For failure to construct and maintain in proper condition slush or mud pits - $10 for each violation.

The federal rules are not explicit in operations such as well plugging or abandonment, and leave much to the discretion of the USGS supervisor. Fines for failure to comply are minimal and the only significant penalty is shutting down of operations and lease concelations.

Montana Laws Regarding Water Pollution (Title 69, Chapter 48)

This law is the basic water pollution law of the State of Montana and is administered by the Montana Water Quality Bureau of the Department of Health and Environmental Sciences. This law defines water pollution and general treatment standards and has an enforcement provision. It prohibits contamination or other alteration exceeding adopted standards of the physical, chemical, or biological properties of any state water. The act not only prohibits pollution, but Section 69-4806(1) states that it is unlawful to place or cause to be placed any wastes in any location were they are likely to cause pollution of any state waters. State waters are defined as: "...any body of water, irrigation system, or drainage system either surface or underground."

Montana Laws Regarding Water Pollution also require a permit for the following activities which annot be conducted without approval from the Department of Health and Environmental Sciences:

(a) construct, modify, or operate a disposal system which discharges to any state waters; or

(b) construct or use any outlet for the discharge of sewage, industrial waste or other waste to any state water; or

(c) discharge sewage, industrial waste or other waste into any state waters.

It is clear that the law prohibits pollution but the prohibition is dependent upon promulgated water quality standards. For state surface waters such standards have been developed, however, there have been no specific standards developed for groundwater in Montana. The regulatory authority, therefore, under this law relative to groundwater pollution is somewhat limited.

Another important provision of the Montana Water Pollution Law is Section 69-4808.2(1)(c)(iii) which is called the "nondegradation statement". It states:

> The Board shall require that any state water, whose existing quality is higher than the established water standards, be maintained at that high quality unless it has affirmatively been demonstrated to the Board that a change is justifiable and as a result of necessary economic social development and will not preclude present and anticipated uses of these waters.

The intent of this statement is to prevent degradation of high quality waters. In application of the law and water quality standards to effluents, this statement is of major significance. It requires that water quality of receiving waters be kept high and not be allowed to degrade to meet minimum standards.

Montana Water Quality Standards (MAC 16-2.14(10)-S13380)

The Montana Water Quality Standards have been developed pursuant to the Montana Laws Regarding Water Pollution. These standards classify surface waters in the State of Montana with respect to their quality and beneficial uses.

The Water Quality Standards establish maximum allowable changes in surface water quality and establish limits for pollutants which affect prescribed beneifical uses of state waters.

In addition to specific water quality requirements, these standards also have general water quality criteria. A general criteria of importance to mining is that industrial waste is to receive, as a minimum, treatment equivalent to the best practicable control technology currently available (BPCT) as defined by EPA. In cases where BPCT is not defined by EPA, industrial waste is to receive, after maximum practicable in-plant control, a minimum of secondary treatment or equivalent.

These water quality standards do not specifically relate to groundwater, however, wastes disposed into the ground that reach surface waters have, in some cases, been assumed to be under the jurisdiction of this rule.

Montana Pollutant Discharge Elimination System (MAC 16-2.14(10)-S14460)
The MPDES rule is based on the Montana Laws Regarding Water Pollution and the EPA, NPDES permit system and generally regulates all point source discharges to surface waters of Montana. Discharges from federal facilities are regulated by the federal NPDES regulation. All MPDES permits issued in Montana meet the requirements of the EPA or are more stringent than the NPDES rule.

For each discharge to surface waters under the MPDES rule, water quality limitations are established for the effluent. These limitations are based on national BPCT and BAT criteria and are receiving water quality.

This rule makes ground disposal of wastes more attractive. There are few discharges that currently use land disposal but in the future, increasing use of land for disposal is expected. The overall effect of this rule

will be to transfer pollution loads from surface water to groundwater.

Public Water Supply Law (Title 69, Chapter 49, R.C.M. 1947)

This law deals with protection, maintenance and improvement of quality of water for public water supplies in Montana. The Board of Health and Environmental Sciences has supervison over waters used for public supply as well as the function of adopting rules and standards and issuing orders to prevent pollution of public water supplies. This act prohibits pollution of state waters and pollution of public water supplies. This law provides some control over pollution of groundwaters since the U.S. Public Health Service and the National Safe Drinking Water Act (P.L. 93-523) provide specific water quality requirements for water to be used for public water supplies. This law prohibits pollution of groundwater that is used as a public water supply.

Refuse Disposal Areas Act (MAC 16-2.14(2)-S14100)

This rule was adopted to establish standards for solid waste disposal areas and waste management. Wastes are grouped with respect to type of material and relative hazard. Refuse disposal sites are classified with respect to the groups of wastes that they can handle. Any solid wastes generated from old mines would need to be placed into a refuse disposal area. A pertinent section of this rule states: "The disposal area shall be so located as to prevent the pollution or contamination of any waters of the state."

Montana Oil and Gas Regulations (MAC 36-3.18(10)-S18130

The Oil and Gas Division of the Department of Natural Resources and Conservation administers laws and regulations relative to the exploration, production and development of oil and gas in Montana. The Oil and Gas Division has

rules that relate to water pollution problems associated with oil and gas drilling and production. Specific sections of the regulation that relate to water pollution are:

1. 36-3.18(1)-S18130 Restoration of Surface. This requires the owner of any drilled oil or gas well or seismographic shot hole to restore the land surface to its previous grade and productive capability and to take such measures to prevent hydrological effects. This regulation is designed to reduce sediement problems and prevent pollution of groundwater and surface water.

2. 36-3.18(10)-S18070 Drilling-Relating to Reserve Pits. The operator of a drilling well shall construct his reserve pit in a manner adequate to prevent undue harm to the soil or natural water in the area. When a salt base mud system is used as the drilling medium, the reserve pit shall be sealed when necessary to prevent seepage.

3. 36-3.18(18)-S18400 Plugging and Abandonment. Requires that all seismic shot holes be plugged and abandoned by filling with drill cuttings and bentonite. Seismic holes in artesian water deposits are to be plugged by a cement slurry. If followed, this should prevent groundwater pollution from seismic shot holes.

4. Section .228 of the Oil and Gas Rules require wells used for injection of water or gas into producing formations to be cased with "... sound casing" so as not to permit leakage and the casing cemented in such a manner as to protect oil, gas, or fresh water reservoirs.

5. Section 232 of the Oil and Gas Rules governs plugging of abandoned wells. The technique used for plugging must be described (Section 232.3); however, it does not specify a detailed method for plugging to ensure there are no adverse impacts in groundwater.

6. Section 227 of the Oil and Gas Rules governs disposal of salt or brackish water produced and requires disposal in a pit where underlain by heavy clay or hardpan. Where the soil under the pit is porous or closely underlain by sand and gravel, pit disposal is prohibited. This provides protection of groundwater.

Open Cut Mining Act Title 50, Chapter 15, R.C.M. 1947

The Open Cut mIning Act regulates mining and reclamation activities associated with production of bentonite, clay, scoria, phosphate, and sand and gravel, and is administered by the Open Cut Bureau. The purpose of this Act is, in part, to "preserve natural resources, and to aid in the protection of

wildlife and aquatic resources" (Section 2, 50-1502). Under this law, the Department of State Lands enters, with operators, into contracts which provide for reclamation of mined areas, consistent with performance standards of the Act. All operators who mine in excess of 10,000 cubic yards of material are subject to the law (Section 7, 50-1507). Violations of this law are processed through the office of the County Attorney having jurisdicition over the mining area, or are processed by the Department of State Lands.

A few portions of the Act specifically apply to water resources:

(2) The commission may not approve any reclamation plan unless the plan provides that:

(c) where operations result in a need to prevent acid drainage or sedimentation, on or in adjoining lands or streams, there shall be provisions for the construction of earth dams or other reasonable devices to control water drainage, provided the formation of such impoundments or devices will not interfere with other landowners' rights or contribute to water pollution.

Adopted rules and regulations further clarify the Open Cut Act. These rules require that an approved reclamation contract include information on location of natural drainages and other surface waters (MAC 26-2.10(6)-S10130 (i)(b)(iv) and (c)(i)(a,d), estimated water table depth -S10130 (i)(c)(i)(g,e), and a detailed description of how sedimentation and/or water pollution will be controlled S10120, (1)(c)(ii)(a,d). Required information includes diagrams of all settling ponds and other water treatment facilities.

Hard Rock Law (Title 50, Chapter 12, R.C.M. 1947)

Mining of minerals other than oil, gas, bentonite, clay, coal, sand, gravel, phosphate, or uranium are controlled under the Hard Rock Law. This law is administered by the Hard Rock Bureau, Reclamation Division, Department of State Lands.

Sections 1 and 2 of the Act ouline legislative observations and purposes concerning hard rock mining. Protection of water resources is specifically discussed in these sections.

Reclamation is required for all exploration and mining activities regulated under exploration and operating permits. Section 9 outlines the requirements of reclamation plans for operating permits:

> (c) Provision shall be made to avoid accumulation of stagnant water in the mined area...
>
> (e) Where mining has left an open pit exceeding (2) acres of surface area, and composition of the floor and/or walls of which pit are likely to cause formation of acid, toxic, or otherwise pollutive solutions (hereinafter "objectionable effluents") on exposure to moisture, the reclamation plan must include special provisions which adequately control these effluents.

No other provision of Section 9 concern water resources. Major concern in this section is thus expressed about acid mine drainage and other effluents produced from open pits.

An operating permit may be denied under the Hard Rock Act if:

> (A) the plan of development, mining, or reclamation conflicts with the state water ... purification standards

Thus, under the Act, a permit could be denied if a mining or reclamation plan would result in violations of water quality standards of the Water Quality Bureau, or if the reclamation methods proposed could not result in the desired reclamation result.

A number of subsections of Rule 5 - Reclamation Plans - concern water resources:

> D. (1) Where operations result in a need to prevent acid drainage or sedimentation, on or in adjoining lands or streams, there shall be provisions for the construction of earth dams or other reasonable devices to control water drainage, provided the formation of such impoundments or devices shall not interfere with other landowners rights or contribute to water pollution (as defined in the Montana Water Pollution Control Act as amended).
>
> (3) All applicants must comply with all applicable county, state, and federal laws regarding solid waste disposal. All refuse shall be disposed of in a manner that will prevent water pollution or deleterious effects upon the revegetation efforts.

Small mining operations which excavate less than 36,500 tons of material each year are considered small miners and are not subject to any of the performance standards of the Hard Rock Act. A small miner must annually agree (1) not to pollute or contaminate any stream, (2) to provide protection for human and animal life, and (3) not to leave undisturbed more than five acres of ground. Failure to comply with these regulations constitutes a misdemeanor, and is subject to a fine of not less than $10 and not more than $100 (Section 19, 50-1219).

The Hard Rock Act provides the least amount of regulatory authority to the Department of State Lands of the mining laws discussed in this section. Permit denial provisions are vaguely expressed, as are specific enforcement measures.

Montana Strip and Underground Mine Reclamation Act (Title 50, Chapter 10)

This law was passed in 1973 and regulates mining of coal and uranium. After passage of the Federal Strip Mine Law in 1977, applicability of state law concerning coal strip mining became subject to federal review. As of January, 1978, state law was still being applied throughout Montana and no determination of applicability of federal law had been made.

The Montana Strip and Underground Mine Reclamation Act is regarded as one of the nation's most stringent strip mine laws. Sections of the Act specify the nature and timing of reclamation, make operators responsible for degradation of groundwater conditions, and specify criteria whereby a permit can be denied. The Montana Reclamation Division has large discretionary powers to require submittal of substantial amounts of information concerning hydrologic systems. Although laws may be considered stringent, enforcement and administration of laws determine the laws impact.

There are several sections of the Act that relate to water quality. Section 2 of the Act states that the policy of the state is to "protect its environmental life support systems from degradation...prevent unreasonable degradation of its natural resources."

The Department of State Lands reviews all mining and reclamation plans, including plans for water control. Surface and groundwater data is submitted as part of a mining permit application. pursuant to requirements outlined in statute rules and regulations (26-2.10(1)-S10300; S10330), and guidelines (issued 1977). The guidelines comprehensively outline data requirements for a year long pre-mining hydrologic study focusing on delineating aquifer systems, channel conditions, water quality, and water use. Except for the hydrologic data requirements for alluvial valley floor areas required in the rules pursuant to the federal Surface Mining Control and Reclamation Act of 1977 and those proposed by Hardaway, et. al., (unpub.), the State of Montana's hydrologic data collection requirements are the most comprehensive in the nation.

Section 9 of the state law permits the state to prohibit mining in certain areas. Although no land has ever been prohibited under this section solely for groundwater or hydrologic considerations, several subsections do apply to hydrologic systems; including:

> (3) If the Department finds that the overburden on any part of the area of land described in the application for a prospecting, strip mining or underground mining permit is such that experience in the state with a similar type of operation upon land with similar overburden shows that substantial deposition of sediment in streambeds, subsidence landslides, or water pollution cannot feasibly be prevented, the Department shall delete that part of the land described in the application upon which the overburden exists.

Amendments to the act specific provisions prohibiting mining in alluvial valley floors have been repeatedly rejected by the Montana State Legislature. Section 10 (1) of the Act requires that an operator reclaim mined land and take "all measures... to eliminate damages to ... streams...from soil erosion, subsidence, landslides, water pollution, and hazards dangerous to life and property. (Section 10 (2) requires the operator to bury toxic materials, seal tunnels, shafts, and all related discharges, and treat all runoff and groundwater flow in order to reduce pollution of surface and groundwaters.

Section 22 (3) permits a surrounding landowner to sue an operator for damages to his/her groundwater supply. The operator must prove that mining did not adversely affect groundwater systems in a suit of this kind. Section 22 (4) permits a surrounding landowner to sue for damages resulting from adverse impacts of mine drainage.

Proposed In situ Uranium Mining rules

The Water Quality Bureau is developing a proposed rule for in situ mining of uranium. The proposed rule would control discharge of pollutants into groundwater from activities associated with solution mining of uranium. The owner or operator of any existing or proposed source discharging pollutants associated with uranium solution mining into groundwater will be required to comply with a number of permit requirements. Required information will include descriptions and discussion of geology, mineralogy, geochemistry, and hydrology. The hydrologic information basically describes groundwater above, below,and within a two-mile radius of the proposed uranium leach area. The proposed rule requires an approved pond lining, an underground leak detection system, monitoring wells, a plan for handling emergency spills, and for disposal of leaked material. It also requires a detailed description of the proposed recovery techniques including well completion information. Another important section of the proposed rule is restoration of affected groundwater after mining is completed. This rule would require the operator or owner to re-establish groundwater quality in the designated area to levels specified within the rule.

Under the proposed rule, a solution mining permit can be denied for a variety of reasons, including failure to submit required data or an improper or incomplete application. Specific penalty clauses have not been developed as yet.

Although the rule is not in final format, the rule appears to be detailed and provides rigid control of uranium solution mining.

State UIC (Underground Injection Control) Program CFR 40 Part 146

As part of the Safe Drinking Water Act, proposed rules have been developed for protecting underground sources of drinking water. The proposed rule is for areas where underground water sources with a level of total dissolved solids of 10,000 mg/l or less will be protected. It specifies, however, that in contaminated areas aquifers containing more than 3,000 mg/l need not be designated for protection so long as continued underground injection practice will not endanger any underground source of drinking water. The state also will have the opportunity, after public comment and a hearing, to make determinations if an aquifer is not an underground source of drinking water at all and needs no protection. The specific construction, monitoring and operating requirements with which underground injection wells must comply, are set forth in the subparts of this proposed rule applicable to the different categories of wells. Exisiting wells are required to obtain permits within 5 years of the effective date of these regulations and a permit must be obtained for operation of a new well before the operation will be allowed to begin. The rule specifies that well integrity must be determined, and prescribes pressure monitoring requirements. The proposed rule is still in the draft format, however, it appears to comprehensively cover the use of injection wells. Pollution control devices are specified for existing injection wells, including wells used for secondary recovery of oil. This may cause much reworking of existing wells. This has caused substantial concern with the State of Montana and with the oil indsutry. It is thought that many of the secondary recovery operations would be economically unfeasible if substantial funding would be needed to be spent on reconstruction of existing injection wells.

Groundwater Pollution Control Regulations

Water Quality Bureau has developed a groundwater pollution control rule. This rule is in a rough draft format and it is expected that substantial additional work will be done before they are proposed for adoption.

The basic approach in this rule is to require a permit for dishcarging pollutants into state groundwaters. This proposed rule also includes injection wells. The draft rule contains effluent standards for discharge of pollutants into state groundwaters and includes self-monitoring requirements. The objective of this rule is not to eliminate waste discharges into state groundwaters, but to consider such discharges as an advance treatment system that, in many cases, would be preferable to direct discharges of effluents to streams. Controls are provided to protect surface waters and domestic and industrial uses of groundwaters in the state. The rule also does not cover sanitary land fills, oil and gas wells, water injection wells at oil and gas operations, agricultural irrigation facilities, and individual septic tank drainfields. The waters of the state are classified in accordance with their present and future most beneficial use which, in nearly all cases, is drinking water. The draft rule allows the administrator to set other standards in areas where groundwater is unsuitable for drinking water, for example, establishment of boron standards for irrigated water.

This draft rule is in response to a need in Montana for control of activities that may cause, or are causing, groundwater pollution. Other rules in Montana do not adequately address this problem of underground pollution and other laws and rules that do contain provisions to prevent groundwater pollution are not specific or clear in jurisdiction.

Subdivision and Platting Act (Sections 11-3859 through 3876) 1973 A

This Act defines land divisions of less than 20 acre parcels as "subdivisions", and requires that all such subdivisions be reviewed and approved by the local governing body. Property deeds or other conveyances of interest in such parcels may not be recorded unless they refer to an approved subdivision plat. The law requires that local governments adopt and enforce subdivision regulations which specify procedures and design standards for subdivision review and approval. These regulations address several aspects including site characteristics of flooding, high groundwater, topography, and other hazards. The subdivision's effect upon local services, the natural environment, and public health and safety must also be considered.

There are exemptions to the review process, including occasional sales, gifts or sales to immediate family, divisions made for mortgage, lien, or trust indentures, and divisions created by court order. The statutory language has allowed use of some exemptions to create a number of parcels without review. Thus, governing officials are prevented from assessing the suitability of building sites or properly planning to minimize the impacts upon community facilities and services.

County Water and Sewer District Act (Title 69, Ch. 45) 1957

This act authorizes the formation of a county water and/or sewer district in any sub-country, countywide, or multi-county area. Registered voters within the proposed district, and within each included county, petition the county commissioners to create the district. After public notice and public hearing or hearings, electors residing in the district must approve the formation of the district, which becomes an incorporated entity. The district board of directors consists of five persons elected within the district,

plus one appointed by the mayor of each included municipality, and one appointed by the board of county commissioners of each included county having unincorporated territory in the district.

A county water and sewer district may acquire, construct, maintain, and operate water works, sanitary or storm sewer works, reservoirs, etc., which are necessary to store, conserve, supply, produce, convey or drain water or sewage for purposes useful to the district. Useful purposes include municipal and industrial water supply, domestic water supply, and pollution abatement. Districts may accept assistance, borrow money, issue bonds, set fees and levy taxes. This Act could be utilized in mitigating existing groundwater quality degradation, or preventing contamination of public groundwater supplies resulting from domestic waste treatement.

Local Boards of Health (Title 69, Ch. 45) 1967

This Act provides for five member local boards of health to function under the general supervision of the DHES. A local board may serve a city, city and county, county, or multi-county district. Board members are appointed by the governing body or bodies of the area served. As part of its functions, a local board of health <u>may</u> adopt necessary regulations and fees for the control and disposal of sewage from private and public buildings not currently connected to any municipal system. The board may adopt rules <u>not</u> in conflict with rules adopted by DHES on water supply and waste disposal in public accommodations.

Sanitation in Subdivision Act (Title 69, Ch. 50) 1967 A

This Act prohibits the filing of a subdivision plat with a county clerk and recorder, the sale of any lot within a subdivision or the construction of any building or water or sewage system in a subdivision until DHES has

approved the provisions for water supply and disposal of sewage and solid waste. The law applies to division of land for sale, rent or lease which create parcels less than 20 acres in size and to mobile home and recreation vehicle parks and condominiums. The definition of "subdivision" under this act approximates that in the Subdivision and Platting Act described earlier. Certain divisions of land, such as occasional sales and family conveyances, which are exempt from review and approval under the Subdivision and Platting Act are not exempt from DHES review.

Within areas covered by an adopted master (comprehensive) plan, a final plat may be filed without department approval of sanitary facilities if the governing body certifies that municipal water supply and sewage disposal facilities will be provided. However, the plans for water supply and sewage disposal facilities must be reviewed by the department prior to construction of the systems, under the provisions of the Public Water Supply Law, described earlier. Where land is acquired to add to an approved parcel, departmental approval is not required if no dwelling or building requiring water and sewer facilities will be built on the additional land.

The DHES must delegate to local units of government the authority to review the sanitary facilities for subdivisions with five or fewer lots where the local government has qualified personnel to conduct the review.

The department has adopted administrative rules which establish procedures for the submittal, review and approval of subdivisions and has specified standards for their sanitary facilites. Before approving or disapproving the sanitary facilities for larger subdivisions, the department must prepare an environmental impact statement in accordance with MEPA. If a written complaint of a violation is sent to the DHES, the law requires DHES to either hold a hearing or to take injunctive action against the violator(s).

Municipal Revenue Bond Act of 1939 (Title II, Ch. 24 R.C.M. 1947)

This Act grants municipalities the authority to construct, operate, maintain, and finance (through bond issues) water and/or sewage systems. It also provides for contractual arrangements with industry for abatement or reduction of water pollution caused by industrial discharges.

Section 11-2202 provides for creation of special improvement districts (SID's) for construction or maintenance of sewers, septic tanks, water mains (and extensions), etc. Public comment is obtained through a hearing process. The Act also delineates the rights of a city to establish sewage treatment and disposal plant systems, and water supply and distribution systems (Section 11-2217).

This authority can be used by municipalities to upgrade domestic (and other) waste treatment systems to adequately protect groundwater quality. However, system design must also consider effects upon surface water resources.

Other Applicable County Regulations

Several other statutes exist which give counties a measure of control in managing the groundwater resource. The following sections of the law could be applied toward mitigation of existing groundwater qualtiy problems or prevention of future problems associated with domestic waste treatment.

The statutes under Title 16, Chapter 16, R.C.M. 1947 provide for the creation of rural improvement districts in populated localities outside limits of incorporated towns and cities. The county may pursue construction or maintenance of sanitary sewers, waterworks plants, and water systems within such districts. Counties also have the authority to organize and incorporate water and/or sewer districts for pollution abatement, water supplies, and other purposes; associated bond issues may be developed.

The Code (Title 16, Chapter 44, R.C.M. 1947), also provides for creation of metropolitan sewer districts when a sewer system would serve both the inhabitants of a county and those of a city or town within the county. The county operates the sewer district and is authorized to fix rates for services.

Counties may also affect water quality through land use legislation. Such legislation could include zoning restrictions upon certain use of particular lands for the purposes of protecting groundwater quality. Under Title 16, Chapter 47, R.C.M. 1947, counties may adopt interim zoning regulations as an emergency measure (one year limit, with one year extension) while developing a master plan for the area (including hearing and formal adoption procedures). Regulations may control urban use, but agriculture, forestry, and mining activities are specifically exempt.

Another zoning measure (Title 16, Chapter 41, R.C.M. 1947), provides for establishment of a planning district in a previously unzoned area, when petitioned for by 60 percent of the landowners within the district. The rural zoning district may also enforce any adopted zoning regulations.

MONTANA GROUNDWATER PROBLEMS

The impacts of the various land use activities, on groundwater quality, are discussed in this section. Groundwater problems have been documented in relatively few instances, since it is extremely difficult and expensive to thoroughly investigate suspected problems. Specific case histories of suspected or documented groundwater problems are shown in Table 16 following the discussions of land use activities in the Statewide 208 Area. Figure 21, also at the end of this section, shows the groundwater problems associated with brine pits, gasoline and diesel fuel spills, pesticides, wood products, tailings ponds, solid wastes, and sanitary wastes.

Oil and Gas

Major oil producing areas in the Statewide 208 Area are near Cut Bank, in Pondera and Teton counties, in Musselshell and Garfield counties, and in northeastern Montana. Gas producing areas include most of northcentral Montana from Cut Bank to Phillips county. These oil and gas fields are shown in Figure 9.

As described by the Oil and Gas Conservation Commission (1976),

> There were 787 wells drilled in Montana in 1976, including 17 oil and 8 gas new field discoveries, and 11 new pay or significant field extensions. A total of 248 exploratory wells resulted in 25 discoveries for a success ratio of 10.1 percent, up nearly 2 percent from the last year's exploratory success ratio of 8.2 percent. Of the 539 development wells drilled, 106 were completed as oil wells, 264 as gas wells, for a success ratio of 68.7 percent, a substantial success increase of 6.5 percent over 1975.

Oil production in Montana peaked in about 1968 and has declined since. In 1976, Montana produced 32.8 million barrels of oil, of which about 22 million barrels (67 percent) were produced in the Statewide 208 Area. Gas production in the Statewide 208 Area was about 35.3 billion cubic feet, or 86 percent of the entire production in Montana.

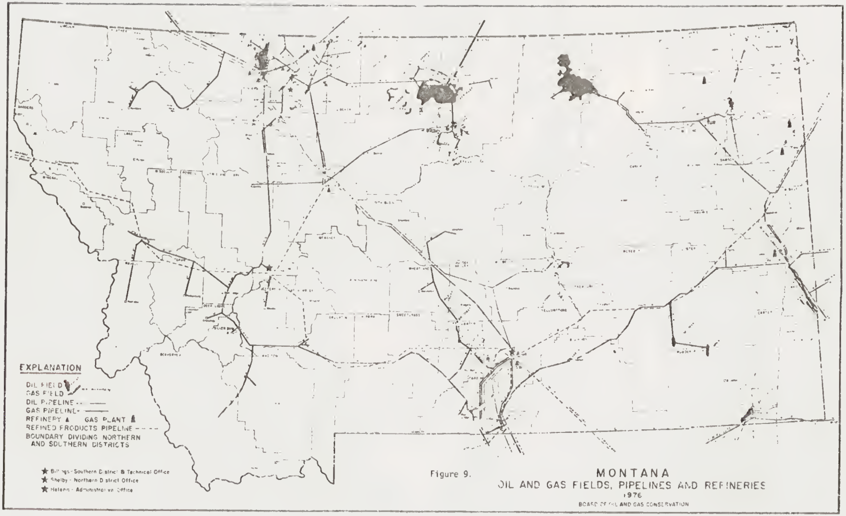


Figure 9. MONTANA
OIL AND GAS FIELDS, PIPELINES AND REFINERIES
1976
BOARD OF OIL AND GAS CONSERVATION

The most important factor in the development of natural gas and oil in Montana is the potential of the Overthrust Belt along the Rocky Mountains in western Montana. As described by the Oil and Gas Conservation Board (1976):

> Interest contniues to grow along the Overthrust Belt in western Montana. Subsurface and surface geological interpretation indicate the possible existance of giant oil and/or gas fields in this area similar to those immediately north of the state boundary.

Substantial work is being done on the Overthrust Belt and large acreages are under application for oil and gas leases from the various forests in Montana. To date, over 2,000,000 acres have already been leased or lease applications are pending. The centers of interest are in the Gallatin, Beaverhead, Flathead, and Lewis and Clark National Forests. Other leasing occurs in a large portion of the Crazy Mountains, areas north of the Absarokee Range, east of Livingston, and in the west Yellowstone area.

The water quality problems associated with oil and gas are characteristic of the phases of production including exploration, development, production, refining, and transportation.

Exploration and Development

A large number of seismic shot holes are used in the exploration phase for oil and gas deposits. Seismic shot holes are usually drilled quickly to depths generally less than 200 feet and are used to place explosives for seismic testing. Many thousands of seismic test holes are drilled annually in Montana, and it is estimated by Bond (1975) that there were approximately 10,000 to 20,000 seismic shot holes drilled per year from the period 1950 to 1970. Results of a study of the influence of seismic shot holes on groundwater and aquifers showed that in thick sequences of marine shales, seismic programs have little or no effect on groundwater aquifers (Bond, 1975).

Other results of this investigation showed that seismic shot holes tend to plug themselves, however, innerflow can, and does, occur in certain situations. In Montana, seismic programs probably have not caused enough innerflow to produce noticeable effects on the groundwater. Seismic holes being uncased, tend to heave, bridge, or cave, effectively plugging the holes.

During the production of oil and gas, wells that are 2000 to 20,000 feet are drilled. In wells of this depth, any breaks in the casing can result in loss of fluids from the wells which can enter into other water systems. Generally, a minimum of two strings of casing are used in oil production wells. Oil production wells are also used for secondary and teriary recovery of oil. These involve either brine solutions in secondary recovery, or brine-detergent solutions containing micellar-polymer surfacants in tertiary recovery. Many older oil and gas wells in Montana were not cemented properly and may have corroded casing which may be allowing some interaquifer transfer of water. No investigation of these problems is known in Montana, and such an investigation would be difficult and very expensive to conduct. Another groundwater quality problem can occur through improperly plugged or abandoned holes. It would be difficult to determine if plugging operations were done properly without being present during the plugging activity, or by checking plugged holes to determine if the cement plugs are properly set at the right locations. If holes are not properly plugged, there is

a chance of intermixing of aquifer fluids should the casing ultimately corrode and leak. Some oil oil and gas wells have flowed after plugs were set indicating a failure of the plugs.

Production

The production of oil involves getting the oil to the land surface, separating it from co-produced brines, on-site storage, and transportation to refineries. Oil production can create several groundwater problems, such as losses of brine or oil into shallow aquifers due to spills, line ruptures, emergency and evaporation pit overflows, or brine seepage. Another problem can be introduction of brines or oil into horizons containing good quality water. This can happen due to failures in the injection or production well casing.

There are an estimated 3400 producing oil wells in Montana and approximately 1000 brine disposal or evaporation pits in use (Water Quality Bureau, 1976). On the average in the United States, about two to three barrels of water are produced for each barrel of oil. Although there are some waters produced in oil fields that are of good quality, the overwhelming majority of waters produced with oil are highly saline.

Major dissolved salts that contribute to the salinity of brines are sodium, calcium, magnesium, sulfate, bicarbonate and chloride. A comparison of sea water and oil field brines is shown in Table 4. These brines can contain significantly more dissolved salts than sea water and as the brines become saltier, the relative abundance of sodium and chloride increases.

Brine produced with oil can be injected into wells used for secondary recovery operations or into wells specifically constructed for brine disposal. A county-by-county summary of brine injection and secondary recovery wells is shown in Table 5 . A complete tabulation of quantities of brine disposed, and water used for secondary recovery is in Appendix III.

The production and disposal system associated with oil wells is shown in Figure 10 . It is estimated that 95 percent of the brine produced in Montana is reinjected and the remaining 5 percent is disposed in evaporation ponds (Water Quality Bureau, 1976). Emergency pits normally present at oil production operations are used during periods of equipment failure that cause spills of brines or brine/oil mixtures. These pits are normally emptied shortly after the emergency situation is over. Every tank battery has an emergency pit as do many of the injection system facilities. Evaporation pits are used to contain and evaporate brines as a disposal method. As shown in Figure 10, oil is pumped from the reservoir to the separator facility that separates oil from production water. The oil is piped to stroage tanks and the brine waste is diverted to a disposal facility which may consist of an evaporation pit or deep well injection, or a combination of the two.

A review of wells used for brine disposal and secondary recovery shows that about 89 percent of the wells are used for secondary recovery and that 85 percent of these are located in Toole and Glacier Counties. The remaining use of wells for secondary recovery and brine disposal is distributed throughout the northcentral and northeastern portion of the Statewide 208 Area.

Table 4. COMPARISON OF SEAWATER AND OILFIELD BRINE

	Seawater (mg/l)	Oilfield Brine (mg/l)
Na^{+1}	10,600	12,000-150,000
K^{+1}	400	30- 4,000
Ca^{+2}	400	1,000-120,000
Mg^{+2}	1,300	500- 25,000
Cl^{-1}	19,000	20,000-250,000
Br^{-1}	65	50- 5,000
I^{-1}	0.05	1- 300
HCO_3^{-1}	?	0- 1,200
SO_4^{-2}	2,700	0- 3,600

Source: Reid et.al, 1974

TABLE 5.

NUMBER OF WELLS USED FOR SECONDARY RECOVERY AND BRINE DISPOSAL IN THE STATEWIDE 208 AREA

County	Number of wells	
	Secondary Recovery	Brine Disposal
Blaine	4	2
Dawson	8	7
Garfield	4	0
Glacier	323(62%)	6
Hill	0	2
Liberty	18	0
McCone	1	8
Musselshell	18	1
Petroleum	18	0
Richland	0	3
Roosevelt	0	21
Sheridan	20	7
Teton	0	7
Toole	107(21%)	0
	521	64

Source: Oil and Gas Conservation Division, September, 1977 unpub. data

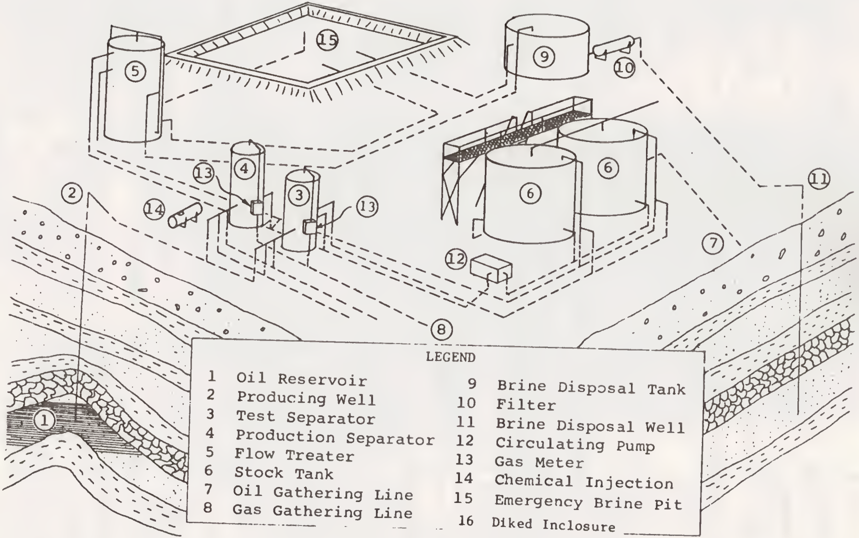


Figure 10. Oil Production-Disposal Scheme.

According to the Montana Oil and Gas Commission, there are approximately 800 oil and gas secondary recovery wells currently active in the state. 23 percent of these inject fluids with greater than 10,000 mg/l total dissolved solids. In addition, there are 68 oil field wells that inject produced waters into zones other than the production zone. Of these, 52 involve fluids with greater than 10,000 mg/l total dissolved solids. The majority of the existing injection wells in Montana are used for water drive to stripper wells, that is, wells producing less than 10 barrels per day.

Excessive seepage from an emergency pit is not allowed. Detection of seepage is based on visual examination of conditions peripheral to the pit and it is estimated that, during spring runoff, most of the pits contain water and that 30 percent of the pits contain water most of the year (Water Quality Bureau, 1976).

In 1976 the Water Quality Bureau obtained information from a number of operators and agencies in Montana concerning possible problems from oil production activities in Montana. At that time, the only problem known was a salinity problem in a well near Cutbank that may have been caused by brine injection.

Other problems within the Statewide 208 Area that have occurred are brine leakage from pits in northeastern Montana. In response to complaints from landowners and, at the urging of a state senator, the Water Quality Bureau investigated five oil fields in northeastern Montana to look at alleged problems associated with brine water disposal. Goose Lake, Dwyer, Raymond, Outlook and Murphy fields were examined. The Goose Lake field is covered by a mantle of glacial till consisting essentially of sand and silt, clay and gravel. This till may be exposed at the surface or lie a few feet below a

covering of soil and may vary in thickness from a few to a maximum of 70 feet. The glacial till is porous and is always permeable where it consists of sand and gravel loam; any pit bottom of such materials is subject to seepage. According to Gorman (1975), the Goose Lake field had ponds that were unlined, evidence of trees killed by brine spillage, abandoned wells that were flowing water, and soil damage by salt water. Most of these problems were corrected after the initial field report was completed.

Salt water pollution from a leaching pit was alleged to have caused damage to a water well used for domestic purposes located in Section 33, T36N, R58E of the Goose Lake field. Quality of salt water taken from the tank battery at the nearby oil production facility and water taken from the domestic well shows a very high concentration of sodium chloride in both waters with the tank battery water being essentially a sodium chloride brine. The explanation offered was that the water in this well may have been damaged by leakage from the disposal pit. Subsequent to the leakage, the oil company was directed to either discontinue use of the disposal pit and backfill it, or to line the pit with a suitable material to prevent leakage (J. Sweet, pers. comm., 1975).

There have been persistent complaints of groundwater pollution in the Cut Bank - Sweetgrass area. Several owners of wells had complained to the Montana Water Quality Bureau that nearby oil production was causing a pollution of groundwater about 10 miles west of Sweetgrass. Complaints were received from an area 9 miles west of Sunburst and 1½ miles west of Cut Bank. Samples from these wells did not confirm pollution from petroleum activities. Additional complaints have been received by the Water Quality Bureau (D. Pedersen, pers. comm., 1978).

The Dwyer field (T32N, R58E) was examined by Gorman (1975). He stated that:

> The emergency pits appear to be unlined and are full of oil-covered water. This area is in a flat valley drained by Brush Mountain Creek and Lake Creek. The soil is sandy and water appears to seep into the ground quickly. There has been concern at the Medicine Lake Refuge that the poor procedures at this field may affect the Medicine Lake Refuge."

No specific problems were described and the present status of the reported unlined pond is unknown.

At the Raymond Field (T36N, R54E) an oil spill complaint was received by the Water Quality Bureau, however, a field investigation showed no problems with oil and discharge pits that were presently being filled. No detailed information was obtained at this field.

The Outlook field (T36N, R52E) revealed an unlined pit with water conductivity of 7300 umhos. Gorman (1975) described the area:

> The land south of the pit was barren for at least 100 feet by 50 feet. There were deep, eroded trenches leading from the pit to the tank batteries ..."

The pit was taken out of service after the site visit.

The Murphy Oil Field is located just north of Poplar. Complaints of crude oil seepage and brine spills were received by the Water Quality Bureau. Inspection of this field showed places where brine had evidently spilled from ponds. A water injection well was found with some water flowing from the well with conductivity of 90,000 umhos (Gorman, 1975). In this field, shallow groundwater appeared to be degraded by brine leakage.

Although there were clearly problems with brine disposal in the fields that were examined, these problems were localized and the main damage appeared to be to small tracts of land and some impacts on groundwater at the Murphy oil field.

Given the magnitude of oil operations in the Statewide 208 Area, a surprisingly small number of complaints have been recorded by agencies that regulate this industry. Many oil operations are in remote areas, thus, there may be few wells nearby that would detect groundwater pollution. There is no detailed state monitoring of brine handling facilities, thus, the magnitude and scope of brine problems is not well known. Of the areas that were examined, problems were present - particulary the use of unlined pits that allow seepage.

Brine handling is common to all oil fields in Montana, and a large number of injection wells and disposal ponds are present. It is the impression from discussions with numerous people, and from examination of brine problems, that the oil industry is becoming more careful in their operations and are creating fewer problems. The overall impact of brine disposal on groundwater quality in the Statewide 208 Area is poorly known.

A detailed investigation involving brine pollution of a fresh-water aquifer in southwest Arkansas was made by Fryberger (1972). Oil field brine was improperly disposed through an unlined evaporation pit, and later, a faulty disposal well. It is estimated that the brine will spread to affect 4½ square miles and remain for 250 years before being flushed naturally into the Red River.

Although real economic damage results from this brine pollution, rehabilitation is not now economically justified. The report emphasizes that greater effort is needed to prevent such pollution which not only affects groundwater resources, but also affects water quality in interstate streams.

Refining

Once the oil is produced it moves from the field to a refinery. Refined petroleum products are used and stored nearly everywhere, and by everyone. Products range from tires to shirts, and from gasoline to asphalt. Refineries are the sources of most liquid fuels as well as numerous byproducts ranging from elemental sulfur to phenols.

Montana has seven refineries currently processing crude oil, four of which are in the Statewide 208 Area. These four plants, one located near Great Falls, two near Cut Bank, and one at Wolf Point, contribute about 10 percent of the total refining capacity in Montana; the remaining 90 percent are concentrated in the Billings-Laurel area. Four additional condensate plants.(field refineries removing light ends (propane, butane, etc.) are located near major oil fields, three in the Williston Basin, and one in the Sunburst area.

Spills of processed fuels can occur at any location, as well as at many points along their distribution routes. Another concern is the concentration in the groundwater of refined products and byproducts that occur when process wastewater is handled incorrectly.

The potential of groundwater quality problems near refineries is related to the process involved. All crude oil contains some salt water as well as varying amounts of metals. These are washed by a relatively fresh-water stream, and the mixture is separated by an API separator, resulting in clean crude and wastewater containing the salts, metals, and minute quantities of hydrocarbons.

Other processes include catalytic cracking, catalytic reforming, desulfurization, isomeration, dractionation, deasphalting, and chemical feedstock extraction. Depending on the crude being refined and the processes used,

a variety of pollutants could enter the wastewater treatment system. The protection of groundwater quality depends on how this wastewater is handled.

Cooling water is often treated with hexavalent chromium to reduce corrosion in piping systems. The chrome enters the wastewater stream periodically during blowdown (back-flushing of cooling water). There has been an attempt in recent years to replace the chromium with much less toxic molybdenum compounds.

Groundwater contamination by petroleum products is known to occur near two refineries in the Billings-Laurel area. The types of waste treatment processes used by these operations and more lenient waste discharge regulations in the past, have led to these problems. No problems due to refined petroleum products are known to occur in the Statewide 208 Area. It is suspected, however, that some petroleum products or byproducts may be affecting groundwater near refineries in the Statewide 208 Area.

Transportation and Storage

Petroleum product contamination from leaky or ruptured pipes, storage tanks or faulty valves can directly enter and affect aquifer systems. The principle contaminant within the Statewide 208 Area from these sources are petrochemical products - gasoline and fuel oil products. Potential contamination from petroleum products is great, due to the vast quantity of supply in the state. During 1976, 29,736,442 barrels of crude oil were transported by pipeline within the state (Oil and Gas Commission, 1976). There are approximately 15 oil pipeline companies operating in the state, and a similar number of gas pipelines. Two of the largest companies contacted represented over 3500 miles of pipe laid in the state; exact mileage figures on the other companies were not readily available (Montana Power Company pers. comm., 1977).

Petroleum products are also transported by rail and truck in the Statewide 208 Area. There have been accidents and petroleum spills from all these transportation modes, however, the only reported problems of groundwater pollution have been from pipeline transport of refined products. Crude and product pipelines in Montana are shown on Figure 9 . A crude oil line transports crude oil from the oil field to the refinery. A products pipeline transports refined product from the refinery to a pipeline terminal where it is distributed by truck to service stations and bulk distributors. Liquid pipelines are almost equal to the length of railroads in the United States and rank second only to railroads in inter-city ton mileage of freight, moving over 23 percent of the total goods shipped as inter-city freight. Liquid pipelines move almost 47 percent of all petroleum in domestic transportation. As described by Johnson (1974), the total mileage of liquid pipelines in Montana exceeds 3,000 miles and on a daily basis, these pipelines transport over 300,000 barrels of crude and refined products. The equivalent movement by transport trucks would require over 1200 trucks per day.

Nearly all the liquid pipelines are buried underground. Pipelines normally are installed in accordance with industry standards and in accordance with Federal Department of Transportation's regulations. Another aspect of pipeline transportation is protection from corrosion. This is done by a coal tar enamel coating and by cathodic protection. Pipelines are equipped and monitored to sense pressures, and to control the flow of liquids. Periodic static pressure tests determine if fluid is lost from the line. A tabulation is kept between product input and product output to also detect shortages in product that may have been caused by pipeline leakage. Pipelines also are patrolled by air every two weeks.

Although a great amount of liquid petroleum is being transported by pipeline in the Statewide 208 Area, including crude and refined product, there have been few spills and few groundwater problems reported. There has, however, been no intensive investigation of the relationship of transported petroleum products and groundwater quality.

Within the Statewide 208 Area there are an estimated 3000 to 4000 steel gasoline storage tanks buried at filling stations, and 20-25 miles of underground pipelines connecting these tanks to the pumps. This is based on the number of gas stations in seven towns in Montana (Table 6), assuming three gas tanks per gas station and assuming similar per capita distribution throughout the remainder of the Statewide 208 Area. In comparison to the number of gasoline tanks, the number of documented leakages are suprisingly small.

TABLE 6.

NUMBER OF GASOLINE STATIONS IN SEVEN REPRESENTATIVE COMMUNITIES IN THE STATEWIDE 208 AREA

Community	# of Stations	Population
Missoula	115	29,497
Hamilton	10	2,499
Glasgow	23	4,700
Sidney	7	4,543
Great Falls	117	60,091
Choteau	5	1,586
Cut Bank	8	4,004
TOTALS	285	106,930

The office of the State Fire Marshall indicated that there are 726 bulk plants in the state; each with a number of 50-100,000 gallon tanks for storage (State Fire Marshall office, pers. comm.,July,1977). The inspection rate and procedure is varied in intensity throughout the state. In some communities, industry provides its own supervision of installation and maintenance of bulk tanks and service station storage tanks; in other communities petroleum handling facilities are periodically inspected through the local Fire Department personnel (Lewis and Clark Co. Fire, Dept.,pers. comm., 1977). Twenty fire departments in Montana communities were contacted by phone to determine the extent of losses of petroleum products; six communities within the Statewide project area had had recent fuel leaks from service station or bulk storage tanks. Two of the situations involved significant amounts of gasoline; one over 10,000 gallons.

Buried metal storage tanks and associated piping are particularly vulnerable to leaks unless replaced frequently or protected from corrosion. When metal tanks and pipes are placed into a subsurface environment, an electrical potential exists between the ground (cathode) and the metal surface of the tank (anode). An electrical current flows when this potential exists, from anode to cathode, and is the main cause of corrosion of metal placed in the ground. Cathodic protection is the name of a process that reverses the potential enough to protect metal tanks from corroding.

There are several methods of cathodic protection, including an impressed current and a sacrificial anode. A sacrificial anode is another metal with a higher potential than steel, for example, a zinc anode, which will corrode while protecting the steel tank.

The EXXON Company is an industry leader in the widespread use of cathodic protection for fuel products tanks at retail stations. It has a program for periodically testing installed systems and evaluating them to verify that protection is taking place. The procedure involves reading the electrical potential of the structure (steel tank) relative to the potential of a copper-copper sulfate half cell in contact with the soil at a designated location (usually the test station) (EXXON Company, U.S.A., 1977). According to EXXON, the readings obtained are usually in the range of a fraction of a volt to a few volts, and structures are normally more negative than the half cell. The potentials and potential shifts must equal certain predetermined standards to verify protection.

Three criteria are checked by the test and it is necessary for all buried metal structures to meet partial compliance. Only the most important facility, such as product tanks, natural gas lines, and lifts are tested for all three criteria. EXXON intends to continue to develop procedures that will facilitate and enhance installation, surveying, and evaluations. The normal desired level of power usage for impressed current cathodic protection is about 75 watts or less. Installations in Montana average less than 40 watts per store (Matney, 1977). This seems to be a reasonably cost-effective protection system.

The overall objective of the EXXON program is to determine the length of time that cathodic protection techniques will adequately protect buried facilities, and to develop a preventive maintenance program of replacing tanks and pipes before they fail. This sort of program results in better protection of groundwater quality from petroleum products.

If a leak of gasoline, oil or chemical fluid occurs in the soil zone above the water table, it will either remain in the vicinity of the leak, move

within the backfill in the trench or excavation, or migrate downward through the natural soil under the influence of gravity. The actual rate and route of travel taken by the pollutant depends on several factors including the volume of fluid released, the comparative permeabilities of the soil materials in the vicinity of the excavation, and the density, viscosity, and miscibility of the liquid. If enough of the fluid enters the soil system so that adsorption on soil particles does not completely exhaust the amount, the pollutant eventually may reach the water table and, if miscible with water, extend into the saturated zone, adding to the contamination of the water table aquifer.

The rate and direction of movement of spilled or leaked material is generally downward until an impermeable horizon is encountered or until a groundwater table is encountered. As the material moves, some portions of the petroleum compounds attach themselves to soil particles and stay bound to these particles. Soils have the capability of immobilizing a certain amount of oil per volume of soil. Products that reach the groundwater table will move along with the groundwater and be transported in the direction of movement of the groundwater. Along this transport route, the petroleum product will continue to be immobilized as it moves. The vapor pressure of many petroleum products is high and if these products are lost in a shallow aquifer, some evaporation can be expected and aging of the material will occur.

McAuliffe (1966) describes petroleum as follows:

> Petroleum is a very complicated chemical substance and is composed of three basic groups; the parafins, cycloparafins, and aromatics. During the refining process, the distillation procedure separates the various petroleum products including gasoline, kerosene, fuel oil and heavy oils.

Most gasolines are a complex mixture of parafins, napthenes, olifins, and aromatics which contain low boiling compounds as well as smaller quantities of high boiling point hydrocarbons. Although it is normally considered that gasoline or oil are not soluble in water, this is not true, as most oil products contain some soluble materials that can, and do, enter in to water and create odor problems. Benzene, for example, has a solubility of 700 mg/l in water (Perry and Chilton, 1973).

Gasoline has been reported to have an odor in water at concentrations as low as .005 mg/l (McKee and Wolf, 1963). The petroleum compounds in gasoline are soluble enough in water to create an odor problem in water and can become dispersed in surface and groundwater bodies. The commonly held concept that petroleum products will "float" on top of the groundwater table is not true, and has been domonstrated in a number of cases of petroleum product contamination in Montana.

There are seven known groundwater pollution problems from petroleum products in the Statewide 208 Area. These specific cases are briefly summarized to illustrate the nature and effect of petroleum products on groundwater quality.

Gasoline and Fuel Oil Pollution - Deer Lodge

In April, 1972, the main municipal supply well was shut down in Deer Lodge, Montana, due to complaints of strong gasoline odors in the system. A technical investigation of the problem was conducted by Botz (1972). Geologically, the Deer Lodge area is underlain by a shallow, unconsolidated alluvial aquifer consisting of a loamy soil and silty clayey gravel overlying a sandy gravel. The gravel layers appear to be stream-deposited and contain moderate amounts of pebbles, cobbles and boulders. The shallow aquifer is underlain by an unknown thickness of layers and lenses of sand, clay, gravel and sandy clay. There are two ten-foot thick clayey layers separating the shallow aquifer from deeper gravel zones tapped by the 150-foot deep municipal well.

Hydrologically, the shallow aquifer has groundwater movement toward the nearby Clark Fork River. Groundwater in this aquifer is recharged by precipitation, seepage of irrigation water and from streams and ditches; aquifer discharge is to the Clark Fork River. Based on drilling logs and general hydrological considerations, it was concluded that the shallow aquifer is not connected or is poorly connected to the underlying aquifer supplying water to the municipal supply well. The relationship of the gasoline pollution area and the municipal supply well is shown in Figure 11 .

Examination of the municipal supply well showed the water surface in the well to be covered with gasoline. This well number was drilled in 1946 and cased with 17½ inches I.D. (inside diameter) concrete casing with perforation in the bottom 68 feet. Removal of the pump showed about 0.9 feet of fluid on the water surface having poor electrical conductivity. Samples skimmed from the surface showed it to be essentially pure gasoline. Seepage of fluid was observed entering a joint in the concrete casing 6.8 feet beneath the pump base and the sides of the well were coated with a slimy mass below the observed leak. Samples of the leaking material indicated a strong gasoline odor. The well was rehabilitated by installation of a peripheral drain to lower the water table below the leaking joint and installation of a steel liner cemented with a special non-shrinking cement to prevent any joint leakage. The well was cleaned, flushed, recleaned, and sterilized and returned to service June 2, 1972, and has been operating successfully since.

It was reported by community officials in Deer Lodge that in 1970-1971 a partially full tank car of diesel fuel was accidentally spilled into the ground at a location several hundred yards from the Clark Fork River. This diesel fuel was discovered to be migrating toward the Clark Fork River in

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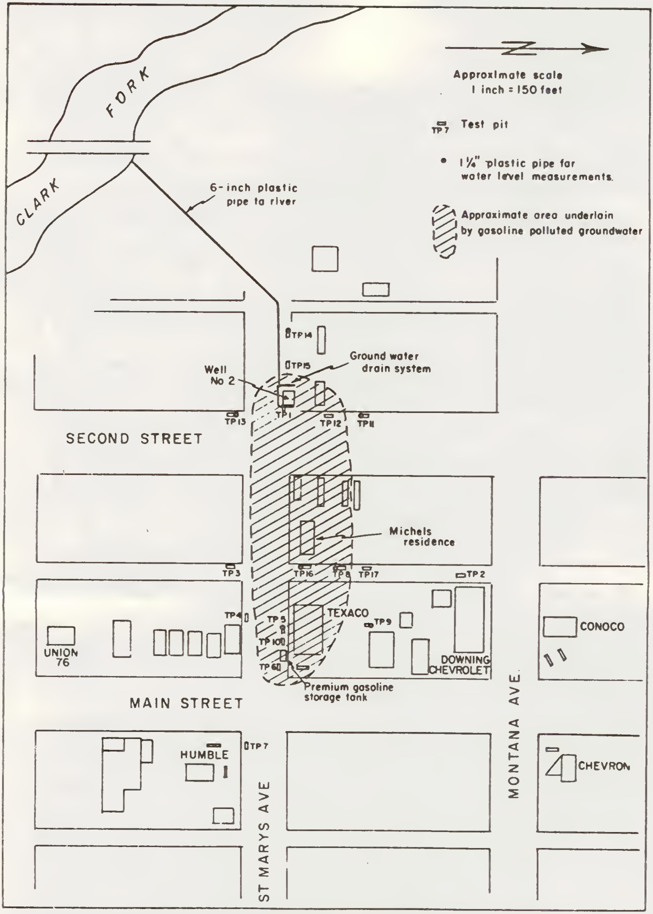


Figure 11— Sketch map of area of investigation showing location of service stations, test pits and area underlain by gasoline polluted ground water, Deer Lodge, MT.
Source: Botz, 1972

reported to have gasoline odors beginning about September, 1972. It was estimated, based on shortages in the pipeline input/output accounting system, that approximately 3,000 barrels (126,000 gallons) of gasoline were lost.

The Missoula valley is a large, intermountain valley, and contains a large supply of groundwater which is replenished by runoff from the surrounding mountains. In the Grant Creek area, near the gasoline spill, the streambed is composed of unconsolidated gravels, sands and silts which form a good aquifer. The gas spill was in alluvium along the stream channel and the gasoline subsequently migrated into an alluvial fan developed from outwash from the Grant Creek drainage basin. Wells in the area range from about 50 to over 150 feet in depth with water levels generally 60 to 100 feet below the ground surface. The alluvial materials have an abundant supply of groundwater and the gasoline-affected well had a water yield of 600 gpm.

The groundwater gradient is quite steep, and generally follows the area's topography, that is, it slopes from the mountains towards the Clark Fork River. There are several other wells downgradient from the gasoline spill, however, no other wells reported gasoline pollution of their water supplies. New wells were drilled, carbon filters were installed, and eventually, gasoline pollution in the aquifers became less noticeable with time and eventually could not be detected.

Gasoline Pollution - Conrad,Montana

In March, 1975, a retail gasoline station in Conrad reported a loss of 10,000 to 12,000 gallons of gasoline. A nearby resident reported gasoline and oil in his basement and heavy fumes (Clasby, M., 1975).

Examination of the problem by the Water Quality Bureau indicated gasoline fumes in the basement in June, 1975. Apparently, the gasoline was being

carried into the basement by groundwater. The water table was approximately seven to eight feet deep in September, 1975, soils were heavy, silty, and clayey with streaks of fine gravel. Gasoline was present in the groundwater and a corrective program was outlined to determine direction of groundwater movement, methods of control, and positive identification of the source (Water Quality Bureau, 1975).

Diesel Fuel Spill - Glendive

Another petroleum spill was in Glendive, Montana, at a service station, where it was reported that 18,000 gallons of diesel fuel were spilled on the ground (Water Quality Bureau, 1975). The spill was about 2,000 feet from the Yellowstone River and 3,000 feet from the Glendive Creek. Soils in the area are a medium textured silt loam underlain by clay. There were no water supplies in the area. No groundwater contamination problems were reported as a result of this spill, but it is not known whether any detailed investigation of this spill was ever conducted. The City Engineer had indicated that he would examine the area and determine if there were any problems.

Diesel Fuel Pollution - Livingston

Diesel fuel has been identified in a groundwater drain that enters Sacajawea Lagoon in Livingston. Source of the fuel is not known and the problem appears sporatically. The fuel oil may be related to fuel oil storage at a nearby railroad yard, but no detailed investigation of this possible source has been made. Impact of the fuel is to surface waters at the drain outlet where a film is occasionally present in the water. This problem is under active consideration by the Water Quality Bureau.

Outside the Statewide 208 Area, other petroleum product spills have occurred and have created much the same effects. Near Bozeman, gasoline moved about one-half mile in about two years and caused pollution of domestic and municipal wells.

In Broadus, over 2500 gallons of gasoline were recovered near a service station. About 12 inches of gasoline overlay a shallow water table. Heavy gasoline fumes existed in the county courthouse and the basement of a nearby business place until abatement procedures were taken. No wells were known to be affected by this leakage.

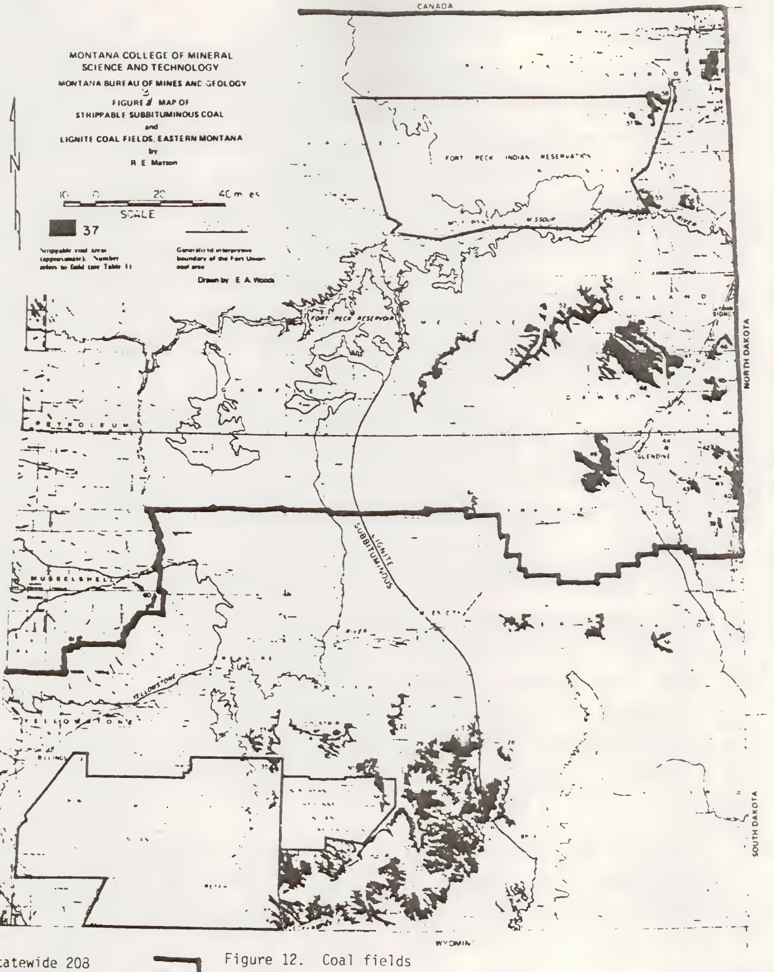
Coal

Montana has one of the largest deposits of strippable coal in the United States. Schmidt and Botz (1978) described in detail the sources of supply, demand, and technology involving coal production in the Statewide 208 Area.

Montana Occurrence

In Montana, vast reserves of coal and lignite occur in much of the eastern and northcentral parts of the state (Figure 13). At the present time, development is focused on the Powder River Basin, outside the Statewide 208 Area, where there are thick, continuous seams of subbituminous coal. Major lignite deposits are generally found east of Miles City. The Bull Mountain area north of Billings has reserves of subbituminous coal, as do portions of Hill, Blaine, Liberty, Choteau and Fergus Counties. Much of the coal in these areas occurs in seams less than 30 inches thick and is discontinuous. Smaller areas along the front of the Rocky Mountains near the Canadian border and also between Great Falls and Lewistown have discontinuous deposits of bituminous coal. Present activity in these areas is limited and small. The total coal reserve base of Montana is estimated to be 108 billion tons, which amounts to over 25 percent of known coal reserves in the entire United States.

Coal fields of the Statewide 208 Area with high or moderate potentials for development, include the Bull Mountains (Musselshell); North Central field (Liberty, Hill, Blaine, Choteau); Wibaux field (Wibaux); Little Beaver field (Wibaux); Four Buttes field (Wibaux), fields in Dawson and Richland Counties; the Redwater River area (McCone and Dawson); and Weldon-Timber Creek field (McCone).



Statewide 208 Study Area

Figure 12. Coal fields

Lignite development is projected in three areas: (1) Dreyer Brothers' Circle West Ranch, a wholly owned subsidiary of Burlington Northern, Inc., in McCone county, at one million tons per year in 1984, increasing to five million tons per year in 1985 and thereafter; (2) Knife River Mine at Savage, increasing from the present 300,000 tons per year to 400,000 tons per year in 1979 and thereafter; and (3) the Wibaux area.

If coal production expands in the Statewide 208 Area, it will take place in eastcentral Montana, a region where lignite is presently produced at the Knife River Coal Mining Company Mine near Savage, Richland county. No significant water quality problems have developed at this mine, which is located about five miles upstream from the Yellowstone River on an ephemeral drainage. This mine has applied for an MPDES discharge permit for discharge, of mine water through settling ponds, including runoff from disturbed areas. Two small mines operate in the Bull Mountains, Musselshell County, but have not caused water quality problems, due to their small size and location in a dry area.

To date, coal mining in Montana and in the Statewide 208 Area has not been free from water quality problems. A substantial amount of research has been done concerning the general effects of coal strip mining on hydrological systems (Van Voast, Hedges, and McDermott, 1977; Van Voast and Hedges, 1975; McWherter, et.al., 1977). The general conclusion of Hardaway, et.al. (1977) is noteworthy: "There is no strong evidence of chronic water pollution caused by the current coal mining operations in the interior western United States."

Van Voast and Hedges (1975) have shown that the Decker Mine has dewatered aquifers, with measurable effects within two-miles of the mine. Such dewatering is probable with any large excavation. The more significant

questions relate to re-establishment of aquifers and groundwater gradients at the conclusion of mining. In time, when mining and reclamation are completed, flow patterns are expected to be re-established. However, there is little direct evidence in Montana to determine the nature of post-mining groundwater systems. Final Interim Regulations for the federal stip mine bill require that a mined area be returned to its former role in the hydrologic system, including re-establishing the recharge capacity of the area. These regulations essentially require that aquifer systems be re-established. Research at Decker and Colstrip also shows that post-mining groundwater quality is generally inferior to pre-mining groundwater quality (Van Voast, Hedges and McDermott, 1977).

Hardaway, et.al. (1977) conclude: "that spoiled overburden contains groundwater of poorer quality than in nearby undisturbed overburden and water-bearing coal seams, and thus that newly spoiled overburden has the potential, at least in selected circumstances, to produce groundwater of relatively poorer quality."

In no case have the specific impacts of increased mineralization of groundwater from coal strip mining been shown to degrade a regional aquifer system in Montana. No research, however, has been conducted on projecting the impact of concentrated mining on regional systems, such as in the Decker/Sheridan area.

A significant level of protection of surface and groundwater quality in valley fill areas is afforded by the Surface Mining Control and Reclamation Act of 1977 and adopted Interim Regulations. Alluvial valley floors have been mapped in portions of Dawson, Garfield, McCone, and Richland Counties (Schmidt, 1977). Mapped areas include the Weldon-Timber Creek coal field, site of the proposed Circle-West Project (Burlington Northern Railroad).

the Redwater River coal field, downstream of the town of Circle, and the Burns Creek-Thirteen Mile Creek coal field, between Glendive and Sidney.

Coal fields in western Montana have not been investigated for the relationship of alluvial valley floors and strippable coal reserves.

Although only a small percentage of strippable coal underlies alluvial valley floors, mining near these areas must demonstrate that the hydrologic balance of the valley system will be maintained during and after mining. If the present Interim Regulations remain in effect, water quality in valley floor systems will be substantially protected by the alluvial valley floor provisions. Mine operators are required to re-establish aquifers and aquicludes, stream channel characteristics and water quality. Excavations in alluvial valley floors, considered by many to be the most sensitive of all aspects of strip mining, will be carefully monitored in the future.

Coal Conversion

The lignite deposits in eascentral Montana consist of a low-grade coal, low in BTU content with a high weight percentage of water, discouraging longe-range shipment to out-of-state users. Economical development of this resource would probably require that the coal be converted to electricity, gas, fertilizer, or some other high-grade product, in plants near the coal fields. Presently there is only one such conversion unit in the Statewide 208 Area, the Montana-Dakota Utilities steam electric generating plant located at Sidney. A large complex is being built outside the Statewide 208 Area, at Colstrip, with a planned capacity of 2250 megawatts. Also, a 330 MW plant is operating near Billings. Both operations use subbituminous coal produced in the Powder River Basin.

With the huge reserves of coal located relatively close to a large supply of water, Fort Peck Reservoir, eventual development of coal conversion plants seems probable. Burlington Northern Railroad has indicated plans to construct an ammonia fertilizer complex which would manufacture methanol and diesel fuel. An industrial steam plant would be built in conjunction with the conversion facility for electrical generation and process steam. Other plants are probable, but a large number of developments is not likely due to the enormous investments required.

Should large steam-electric generation complexes be built in the Statewide 208 Area, the impact on groundwater may be similar to the Colstrip operation. Cooling tower blowdown, brine and ash disposal are potential sources of groundwater pollution. Production, amounts and types of wastes are specific to the conversion process. Well designed and operated containment systems for wastes can protect groundwater resources. The waste disposal system at Colstrip for the two 350-megawatt steam-electric power plants is a closed-loop system with minimum impact on groundwater resources (Botz, 1978).

A number of technologies are being evaluated for the conversion of coal to methane, methanol, ammonia, and heavier liquid fuels. The basic process involves the hydrogenation of carbon to produce hydrocarbons similar to petroleum products. Hydrogen is almost always produced by chemically splitting water molecules into its basic elements. This is done by reacting carbon (coal), carbon monoxide (partially burned coal), and steam. The temperatures and pressures involved depend on the process used and give the operation its characteristic efficiency as well as its characteristic chemical by-products.

In the production of steam, any wastewater generated will have essentially the same qualities and problems involved with steam-electrical generating plants. The production of gas and liquid hydrocarbons presents an entirely different situation.

Coal is not pure carbon, but a complex mixture of carbon, linear hydrocarbons, aromatics (cyclic hydrocarbons), ash (clays and metals) and sulfur (inorganic and organic). When this raw material is forced into a reaction chamber and combined with hot steam at varied pressures, a number of reactions are possible. In gasification plants the main products are methane, carbon dioxide, sulfur dioxide, and depending on the process, nitrogen and nitrogen oxides, and minute quantities of other chemicals. If the gas were to be used on site, e.g. for electrical generation, it would probably not be scrubbed before burning and any water quality problems would again be similar to present day steam-electric units. In Montana, however, the low-value gas would most likely be scrubbed of carbon, sulfur, and nitrogen oxides before being reacted further to methanol, ammonia, or diesel, or methane shipped via pipeline to distant markets. It is in the scrubbing process that wastewater, other than cooling water, is generated. Besides removing the oxides, small amounts of phenols, cresols, benzene, napthalene, and other exotic chemicals are dissolved in the scrub water.

Since most of the technologies for coal conversion are in the development state, there is little information available concerning the amounts, and types of wastes generated. In situ gasification could cause degradation of groundwater due to generated wastes. An experimental program in the Hanna Coal Field in Wyoming, was authorized by the U.S. Bureau of Mines to field test underground gasification and should provide some information on its potential for groundwater contamination (Fischer and Schrider, 1975).

Recent innovations in coal gasification include plans designed for zero discharge of wastewater. Any wastewater streams, such as recylced scrub water is used to slurry coal into the reactor. The ash content of the coal plus the mineral content of the slurry water form clinker in the bottom of the reactor and is conveyed away for disposal as a dry solid (Chemical Engineering, Oct., 1974).

Uranium

The mining of uranium is discussed by Schmidt and Botz (1978) and is summarized as follows:

In the Statewide 208 Area uranium was discovered in the 1950's near Clancy and Boulder, Jefferson County. The deposits occur in quartz monzonite, granodiorite, and related rocks of the Boulder batholith. In these areas, the uranium is associated with vein zones which also contain, in places, lead, silver, zinc and copper. From this area, a few hundred tons of ore have been produced and no current mining is taking place.

Other uranium deposits in the Statewide 208 Area are located near Saltese in Mineral County, in Ravalli County, in Beaverhead County, in the lignite deposits of eastern Montana, in the shale and lignite beds of Lewis and Clark, Broadwater and Jefferson Counties, and in the bedded phosphorite deposits of southwestern Montana.

The USGS (1968) states:

> If the need were great enough, very large quantities of uranium could be recovered from the uraniferous lignite deposits of eastern Montana and from the phosphorite deposits of western Montana. Montana therefore is an important potential source for the future production of uranium.

There are existing uranium leases in 14 Montana counties, ten of which are in the Statewide 208 Area (Table 7). Prospecting is currently underway in fifteen counties, ten of which are in the Statewide 208 Area (Table 8). Although prospecting and leasing in Montana are active, no commercial deposits have been announced. The most promising deposits, in Carter County, are outside the Statewide 208 Area. It appears that near future (next 10-15 years) possibilities for development of underground or open-pit uranium in the Statewide 208 Area are poor, and solution mining will depend on discoveries of commercial deposits.

TABLE 7

Existing Uranium Leases in Montana as of November 1, 1977

COUNTY	ACRES	COMPANY
BEAVERHEAD	7107	Lucky Mc Uranium Corp.
	440	E. O. Larson
BLAINE	840	Pioneer Nuclear, Inc., etal
CARTER	1920	Montana Nuclear Corp.
	1252	Exxon Corp.
	6728	Kerr McGee Corp.
	540	Frontier Res., Inc.
	800	Mobile Oil Corp.
	1600	Felmont Oil Corp.
	960	Homestake Mining Co.
CHOUTEAU	120	Wyoming Mineral Corp.
FALLON	480	Felmont Oil Corp.
GALLATIN	2080	Lucky Mc Uranium Corp.
HILL	1880	Pioneer Nuclear, Inc., etal
JEFFERSON	7126	Lucky Mc Uranium
JUDITH BASIN	400	Continental Oil Co.
LEWIS & CLARK	1120	St. Joe American Corp.
McCONE	640	Wyoming Mineral Corp.
MEAGHER	2560	Lucky Mc Uranium
STILLWATER	9120	Sabine Production Co.
SWEETGRASS	320	Sabine Production Co.
TOTAL	48,133	

Source: Montana Department of State Lands

Through the Montana Energy Office

TABLE 8

Active Uranium Prospecting Permits
in Montana, as of June 1, 1977

Permittee	County
Anschutz	Carbon
Bur West	Carbon
Bureau of Mines	Missoula and Ravalli
Cominco American Incorporated	Carbon
Continental Oil Company	Jefferson and Mineral
Exxon Company, U.S.A.	Broadwater, Carbon, and Carter
Felmont Oil Corporation	Carter and Fallon
Frontier Resources	Carter
Gulf Mineral Resources Company	Musselshell
Kerr-McGee Corporation	Carter
Mobil Oil Corporation	Carter
NRG	Powder River
Pioneer Nuclear	Carter and Madison
Sabine	Stillwater
Wyoming Mineral Corporation	Fergus, Judith Basin, and McCone

Source: Montana Department of State Lands.

Through the Montana Energy Office

Although mining is not taking place, it is important to consider potential impacts of future uranium development. Aspects of the uranium process where possible effects on groundwater quality might occur, include: exploration activities, various mining methods, and various milling methods. Mining and milling techniques include open pit-acid leach processes, underground mine-acid leach processes, underground mine-alkaline leach processes, and mining processes. Major aspects of potential water quality impacts from uranium mining relate to problems of tailings disposal of processed materials and disposal of toxic liquids in aquifers.

Nationally, a major environmental impact associated with open pit mining is pit dewatering. The establishment of an open pit mine creates a regional drain on the groundwater system similar to that observed at coal strip mines and this dewatering may affect other water users in the vicinity of a mine. Mine waters may contain uranium, selenium, zinc, sodium, sulfates, nitrates, and other substances. The specific composition of the mine water varies with the composition of the aquifers intercepted and the rock formations encountered in the pit.

Generally, discharges from acid and alkaline leach systems range from 250 to 1000 gallons per metric ton of ore processed. Although recycling of liquids reduces discharges, wastes must inevitably be disposed. Waters used in leaching operations must be developed from surrounding wells which have a regional dewatering affect on the system. Liquid wastes from mills are aqueous solutions containing various chemicals, leached elements, and suspended ore fines and other solids. Liquid wastes from milling operations generally are discharged through a settling pond. These solutions from alkaline leach processes have a pH of between 9.5 and 11.0 from the unreacted carbonate-bicarbonate leach solutions. This leaching process is relatively

specific for uranium and does not leach out many other minerals from the ore. A portion of the alkaline process water is discharged to a tailings pond to prevent buildup of dissolved solids while the remainder of the process water is recycled through the plant.

The quantity of seepage from tailings ponds varies depending on pond design. In evaporation-percolation ponds, seepage may account for up to 85 percent of all losses. In lined ponds seepage losses are much less. Excess liquids from tailings ponds may be discharged to streams or disposed of to groundwater aquifers. Discharged waters generally are neutralized and treated to remove metals and other contaminants. Water seeping from tailings ponds may contain many contaminants such as nitrates, sulfates, and trace elements. Ground and surface waters may become polluted. Numerous radiologic studies have illustrated that pollution of ground and surface water can occur from seepage and mill discharge. Contamination of wells by non-radioactive pollutants has resulted in contamination of livestock water in Colorado. Nitrates have polluted groundwater in New Mexico. Trees have died downgradient from a tailings pile in Colorado. Groundwater contamination with selenium and nitrates has been shown to occur near tailings ponds in the Grants Mineral Belt of New Mexico. In some areas where seepage is a problem, catchment basins or wells have been placed downslope from the pond to intercept contaminated water and pump it back to the pond. Surface waters may be contaminated by contaminated groundwater which discharged into ponds or streams (Reed, et.al., 1976).

Liquid waste may also be injected into deep wells for disposal. The disposal zone is usually hundreds of feet below the surface. The disposal zone must be separated from aquifers by impermeable formations and it is important to properly case all injection wells.

Potash Solution Mining

Potash deposits are found in Montana in the northeastern counties of Sheridan, Daniels, and Roosevelt. These deposits are found in sedimentary rocks which range from 7,000 to 9,000 feet below land surface. Conventional mining is not economically feasible in these deposits, and potash in Montana can only be mined by solution mining techniques. No solution mining of potash presently occurs in the United States, however, uranium is solution mined in Wyoming, Texas, and New Mexico. Potash is solution mined near Regina, Saskatchewan.

The term potash generally refers to any potassium mineral sold for its potassium content. The chief potassium minerals are potassium chloride (murate of potash), potassium sulfate (sulfate of potash), and a mixture of potassium sulfate and magnesium sulfate (sulfate of potash-magnesia). In early times, a potassium compound, potassium carbonate, was produced from solutions leached from woodashes evaporated in iron pots - hence the term "pot ashes". About 95 percent of the world's potash is used as fertilizer, and five percent is used to make certain grades of glass, liquid soap, and other minor uses.

Geologically, the deposits mined in Saskatchewan grade continuously into those underlying northeastern Montana and northwestern North Dakota. These deposits, however, increase in depth towards the south. Deposits are found 3,000 feet below the surface near Saskatoon, 5,000 feet below the surface at Regina, and about 7,000 feet below the surface at the U.S. border. The potash ores are derived from ancient seas and are found in three fairly continuous and consistent layers of sylvinite ores in the upper part of an area known geologically as the "Prairie Evaporites". These deposits were

laid down in Devonian time, about 350 million years ago (Kalium Chemical Ltd, plant brochure, no date).

Solution mining near Regina, Saskatchewan, involved the drilling of a series of wells in a cluster from a central drilling pad. The cluster radius develops an area somewhat less than one mile in diameter. An unsaturated solution is pumped down one (or some) of the wells, dissolves the minerals in the evaporate beds, and a brine, saturated in NaCL and KCL, is pumped out other wells in the cluster. Potash is then recovered from this brine through an evaporation and crystallization process which produces large amounts of NaC as a by-product. An extensive plant facility is necessary to produce heat and power for the evaporation and crystallization process and sizing of the potash.

Standard oil field drilling equipment is used for well development, and, at the Kalium Chemicals, Ltd. Plant at Regina, the entire drill holes are cased with cememt. Ore may be extracted from zones up to 100 feet in thickness. Extraction is done from a single bed and an overlying "blanket" is used to extract from other beds. Brine from producing wells is pumped back to a plant in pipelines buried below the surface (Schmidt, 1975).

About 2,000 acre-feet of water are consumed each year at the Kalium Chemicals Plant, where mine production is about 1.5 million tons of potash per year. All surface water within a five-mile radius of the plant is monitored for water quality. The evaporation-crystallization process leads to the production of large amounts of waste salt. At the Kalium Chemicals Plant, some salt is used by a salt company, and the remaining salt is disposed of in a 410 acre pond. Reclamation of salt-covered areas would be expected to create certain environmental problems (Schmidt, 1975).

Although Montana potash deposits are found at a deeper depth than deposits in Saskatchewan, increasing interest in Montana potash is evident. This interest largely has been a function of industry's dissatisfaction with natural resource policies of the Saskatchewan government. In mid-November, 1975, the province of Saskatchewan announced that it intended to expropriate at least half of the provincial potash industry (Engineering and Mining Journal, 1975). Presently, Saskatchewan supplies one-fourth of the world's potash needs. The drive to nationalize the Saskatchewan potash industry may potentially lead to the development of potash mining in northeastern Montana and northwestern North Dakota.

Agriculture

Agriculture in Montana is a big business; a business that accounts for 96 percent (12,450,000 acre-feet per year) of the state's total water use (Ricks, 1975); a business that accounted for an average of 65,000 cattle in feedlots in 1977 (Thorsten, pers. comm., 1978); used 284,000 tons of fertilizer in 1976 (Montana Department of Agriculture, 1976); applied approximately 600 tons of pesticides in 1969 on 3.3 million acres of land (USDA, 1969 and Jackson, pers. comm., 1978). Agriculture is a major economic factor in Montana; five counties (Choteau, Liberty, Toole, Daniels, and Roosevelt) rank among the top 100 counties in the United States in per capita income (U.S. News and World Report, 1977). The agriculture economy in Montana is currently being depressed by low livestock and grain prices, however, this may be a temporary downtrend in a generally improving market condition . Between 1964 and 1976 there was a 400-percent increase in fertilizer sales in Montana (Montana Department of Agriculture, 1976, and 1964). Land and water relationships also are changing rapidly. Through numerous interviews with irrigation supply companies in Montana, it is estimated that 64,000 acres were converted from flood irrigation to sprinkler irrigation in 1977, while over 96,000 acres were converted from dryland to sprinkler irrigation. It is obvious that a land activity of this magnitude has the potential for significantly impacting groundwater quality.

There are five major agricultural activities affecting groundwater quality; dryland farming, irrigation, fertilizers, pesticides, and feedlots.

Dryland Farming

Dryland farming involves an estimated 11 million acres in the Statewide 208 Area (Montana Crop and Livestock Reporting Service, 1977). Much of this land is farmed in a crop-fallow rotation system, a very successful practice in the production of grains and widely used in Montana due to the accumulation of moisture in the soil. This practice, however, causes increase recharge to groundwaters and is the basic cause of saline seep.

Saline seeps are recently developed salty areas in nonirrigated land that have the characteristics of saline or saline-sodic soils. They typically are wet, have salt crusts, and vegetative growth, may be reduced or are characterized by salt tolerant species. There has been a great deal of information developed on saline seeps in Montana in the past several years. The mechanism of saline seep development has been established and investigated in several areas. The basic hydrologic flow system for saline seep formation consists of infiltration of precipitation into a salt-laden soil, dissolution of salt from the soil, downward percolation of the salty water, lateral movement within the groundwater system, and reappearance of the salt-laden groundwater at the ground surface or at a groundwater discharge point. Salts in the groundwater are further concentrated by evapotranspiration creating typical white-crusted saline seep areas. The basic moisture input of the system is precipitation. The saline seep phenomena, as it has been investigated in most dryland areas, is relatively a localized phenomena consisting of water recharge areas and nearby (within a few thousand feet) discharge areas where groundwater is coming to the surface (Figure14). The system is also characterized by a rather shallow aquifer system.

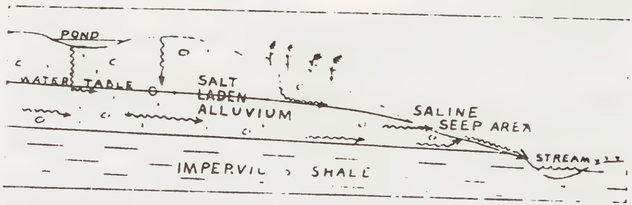


Figure 13 Diagram of saline seep mechanism in shallow aquifer.

Source: Kaiser, Gorman, and Botz, 1975

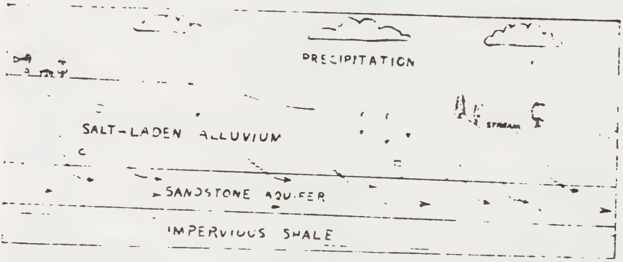


Figure 14 Groundwater salinity from deep percolation of water into a regional aquifer.

Source: Kaiser, Gorman, and Botz, 1975

Another situation where salinity can substantially degrade groundwaters that has not been investigated to date, consists of saline-laden soils or glacial till underlain by a regional aquifer system (Figure 15). In this case, percolating groundwaters enter the salt-laden material overlying the regional aquifer; percolate downward, picking up a a salt load, and then enter the aquifer system to be transported along with other groundwater in this system. Saline water that enters into such a regional groundwater system may not reappear for a considerable distance away from the input source, and it may be difficult to determine a cause and effect relationship in wells that do detect salinity increases. Many of the regional aquifers in the Statewide 208 Area including the Judith River Formation, Eagle Sandstone, Two Medicine Formation, Kootenai Formation, Swift Sandstone, and others, are widely used as sources of domestic and livestock water, and, in some areas, for irrigation. These aquifers are all regional in size and are commonly present beneath glacial tills or saline soils. The groundwater pollution condition illustrated in Figure 15 could occur in many areas. Montana has a low density of wells and water quality samples are seldom taken resulting in a poor ability to detect salinity changes in regional aquifers. It is possible, therefore, that, in places, regional aquifers are becoming saline with essentially no detection of this problem.

Areas affected by saline seep in Montana are shown in Figure 16 and are tabulated in Table 7 . Growth of saline seep affected lands was from an estimated 55,700 acres in 1969, to over 140,000 acres in 1974 (Kaiser, Gorman and Botz, 1975). Total acreage presently affected by saline seep has been estimated by various sources from 140,000 to over 250,000 acres and based on more recent data, saline seep affected land is estimated to be about 200,000 acres (M. Miller, pers. comm., Feb.,1978).

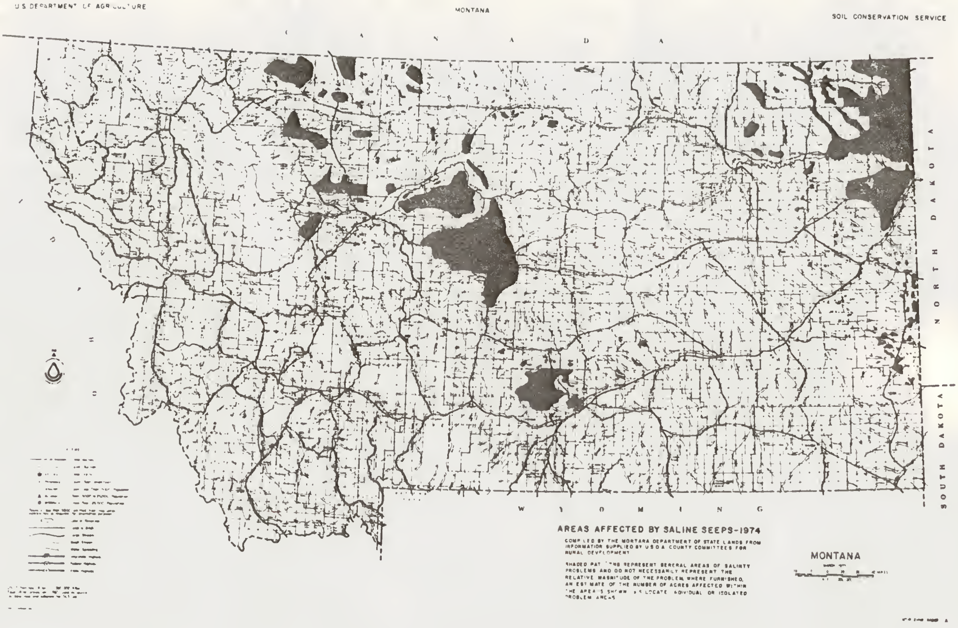


FIGURE 15 Areas affected by Saline Seeps - 1974

TABLE 9

SALINE SEEP ACREAGE ESTIMATES - 1974
RANKED BY SEVERITY OF PRO[illegible]EM

COUNTY	ACRES AFFECTED
1. Stillwater	23,000
2. Chouteau	17,400
3. Fergus	13,848
4. Roosevelt	12,500
5. Sheridan	10,000 - 12,000
6. McCone	10,000
7. Cascade	7,000
8. Toole	6,000
9. Daniels	5,400
10. Liberty	4,600
11. Judith Basin	3,500
12. Richland	1,900 - 3,500
13. Pondera	3,088
14. Blaine	3,000
15. Glacier	3,000
16. Hill	2,000 - 2,500
17. Meagher	2,300
18. Madison	2,060
19. Teton	1,600
20. Phillips	1,500
21. Big Horn	1,000
22. Musselshell	924
23. Valley	800
24. Fallon	753
25. Golden Valley	715
26. Ravalli	[illegible]
27. Yellowstone	[illegible]
28. Lake	[illegible]
29. Wibaux	[illegible]
30. Prairie	[illegible]
31. Carbon	[illegible]
32. Dawson	[illegible]
33. Lewis & Clark	[illegible]
34. Custer	[illegible]
TOTAL	14[illegible],485 - 14[illegible],555

Source: Compiled by Montana Department of State Lands from estimates supplied by County Committees for Rural Development.

Based on an estimated dry cropland area in Montana of 7,226,900 acres, saline seep is impacting about 3 percent of these lands. The rate at which native rangeland is converted to cropland is not well known, but it is speculated that 100,000 to as much as 500,000 acres are converted annually. The recent decline in grain prices has probably slowed this rate.

Montana has already lost much cropland to saline seep and the area affected is growing by over 10 percent a year (Bahls and Miller, 1973). Areas impacted by saline seep include:

A. Northcentral Montana including what is termed the "triangle area" between Great Falls, Havre, and Shelby, and includes Choteau, Teton, Toole, and Pondera counties, and to a lesser extent, Liberty and Cascade counties.

B. Central Montana including Fergus and Judith Basin counties.

C. Northeastern Montana including Roosevelt, Richland, and Sheridan counties, and lesser amounts in Dawson, McCone, Fallon, and Wibaux counties.

D. Southcentral Montana including Golden Valley and three counties not in the Statewide 208 Area, Stillwater, Sweetgrass, and Yellowstone.

About 70 to 80 percent of the saline seep developed in Montana is in glaciated terrain, which is characterized by soils suitable for dryland farming, but, unfortunately, high in salinity. Nonglaciated areas that have saline seep problems are Fallon, Wibaux, Fergus, and Judith Basin counties, and some portions of Golden Valley county.

In southeastern Montana (an unglaciated area), there is little saline seep, There also is less agriculture due to the lack of suitable soils, more rugged topography, and the Fort Union Formation contains only about one-third of the salt load of glaciated areas (M. Miller, Feb., 1978). The most detailed investigation of the areal extent of saline seep was done in a cooperative program between the Montana Water Quality Bureau and the Montana Bureau of Mines and Geology. This investigation, funded by the Old West

Regional Commission, surveyed seep areas east of the Rocky Mountains in Montana on a county-by-county basis. Both aerial mapping and detailed ground survey were made to determine the size and nature of seep areas. This report is currently in press and will soon be available.

Saline seep not only represents a problem in groundwater quality, but much of the saline seep has occurred on prime lands and is a significant economic factor.

Widespread occurence of saline seep, the large acreage directly affected by saline seep, the large area of groundwater impacted by saline seep, clearly makes this one of the major, if not the major, groundwater pollution problems in the State of Montana. With the possible exception of irrigated agriculture, no other activity in Montana has the scope and impact on grounwater quality as does saline seep.

Saline seep impacts agriculture, but also has potential impacts on water supply systems, domestic and stock wells, ponds, reservoirs, springs, and streams. In many saline seep areas, relatively shallow water-bearing formations are a major source of groundwater for towns, domestic use, livestock, and are hydrologically connected to springs, ponds, and streams. This shallow groundwater represents a valuable resource in Montana, and in many areas, there are no economic alternatives to these shallow groundwater aquifers.

In Montana there are about 14 communities with groundwater supplies that have high total dissolved solids, high nitrates, or have a nearness to saline areas that may result in an increasing concentration of dissolved minerals in the groundwater. Data have not been developed to conclusively show deteriorating water quality due to saline seep, however, the slaine seep mechanism is a suggested reason for the poor quality of these water problems (Botz, 1975).

The chemical characteristics of saline seep waters is illustrated in Table 8, which shows these waters to have very high concentrations of dissolved solids - in some cases greater than sea water. They have very high concentrations of sulfate, nitrate, sodium, magnesium, and trace metals. These waters are unsuitable for nearly any use and eliminate or inhibit growth of vegetation.

There are other hydrologic implications from the saline seep problem. It has been observed that there are increases in groundwater levels in much the glacial till area in Montana, and it is suggested that this groundwater storage may be impacting the overall hydrologic balance of the Missouri River system (Bahls and Miller, 1973). The mountains of southwestern Montana form the headwaters for the Missouri River and degradations of water in this area will impact the entire Missouri River system.

Techniques for abatement or elimination of saline seep have been proposed, and, in some areas, have been implemented with moderate to good success. The strategy for correction of slaine seep problems has been to intercept water before it infiltrates into the ground and migrates to the groundwater table. This has been done by continuous cropping and planting of high-water use vegetation such as alfalfa. In some areas on the Highwood Bench, near Fort Benton, Montana, this corrective strategy has been successful in significantly reducing the area impacted by saline seep (M. Miller, pers. comm., Feb.,1978). Also proposed for abatement of saline seep has been drainage systems that intercept groundwater upgradient from the seeep and, thereby, "dry up" the seep. Sommerfeldt (1975) suggested mole drains, which are subsurface channels made by pulling a bullet-shaped object through the soils as a possible solution to soil drainage. Other solutions include standard interceptor drain systems. One problem with

TABLE 10
Analyses of Salt and Water Samples in the Fort Benton Area.
(All values are in milligrams per liter (mg/l) except as indicated.)

Parameter	Salt Sample (micrograms per gram)	Test Hole HC3 (70)	Ground-water Test Hole BF2 (70)	Test Hole D21 (72)	Bramlette Reservoir 1969	Surface Water Bramlette Reservoir 1972	Missouri River at Fort Benton	Recommended Drinking Water Standards
Sulfate (SO_4)	536,000	26,475	33,000	36,730	3,600	5,690	55	250
Nitrate (NO_3)	12,800	2,262	881	918	115	14	0	45
Chloride (Cl)	10,200	168	255	280	57	96	8	250
Bicarbonate (HCO_3)	4,000	878	288	545	334	425	163	
Sodium (Na)	110,000	4,821	7,045	5,600	720	950	42	
Magnesium (Mg)	72,000	4,607	4,546	6,295	498	908	14	
Calcium (Ca)	8,200	341	594	446	215	273	18	
Potassium (K)		41	6	45	16	28		
Strontium (Sr)		22.5	8.1	7.7	2.0	2.4	.22	
Lithium (Li)		2.8	1.1	.99	.28	.38	.04	
Iron (Fe)	3,340	5.1	8.0	1.4	.14	.20	1.3	.30
Manganese (Mn)	112	.87	.70	1.1	.24	.39	.01	.05
Aluminum (Al)	1,108	8.2	8.2	2.0	*.10	*.10	1.0	
Copper (Cu)	5.2	.12	.14	.12	.02	.03	.0[illegible]	1.0
Lead (Pb)	28.0	.78	.78	1.3	.20	.13	*.02	.05
Zinc (Zn)	22.0	1.32	.69	.10	.03	.02	.03	5.0
Nickel (Ni)	9.6	.34	.52	.42	.05	.03	*.02	
Cobalt (Co)		.22	.25	.38	*.05	.10	*.02	
Cadmium (Cd)		.11	.12	.06	.01	.01	*.0[illegible]	.01
Chromium (Cr)		.12	.12	.22	*.02	.02	*.02	.05
Silver (Ag)	1.48	.08	.06	.13	.02	.01	*.01	.05
pH		8.08	8.35	7.46	8.00	7.63	8.00	6.0-8.5
Specific Conductance (micromhos)		26,700	31,750	31,700	5,860	6,110	405	
Total Dissolved Solids		39,690	46,750	50,880	5,566	8,380	307	500

*means "less than"

Irrigation

Groundwater also is affected by irrigation. Water applied to crops by sprinkler systems or by flood irrigation interacts with other materials added to the ground such as fertilizers and pesticides and also reacts with soils and plants to cause changes in groundwater quality.

Optimum production of crops depends not only on a sufficient supply of irrigation water but also depends on an adequate supply of nutrients (usually supplied through chemical fertilizers) and pesticides (for plant disease and insect control). With proper water application, little fertilizer is leached below the root zone. This involves an understanding of soil water capacity, evapotranspiration, surface runoff, crops water needs, and soil and crop nutrient balances. The hydrologic balance involved in proper irrigation is shown in Figure 17 .

Even where proper irrigation management is practiced, a substantial increase in groundwater salt load can occur. For example, all irrigation water contains some concentration of dissolved minerals. Once applied, a small amount, 0 to 20 percent runs off as a surface runoff (irrigation water return) and picks up salts left on the soil surface by evaporation. The remaining water percolates into the groundwater system and serves several functions. Depending on local climates, a certain percentage is taken up by plants to supply their water demands. Water used by plants has a low salt concentration with the salts being preferentially filtered out by the plants and left in the soil profile. Some water evaporates directly from the soil leaving a salt accumulation on the soil surface. The loss through plants and the loss through evaporation of soils are commonly considered together as a consumptive use termed "evapotranspiration". A properly managed system will apply 120-125 percent of the evapotranspiration requirements of the irrigated crop.

drain systems is disposal of saline waters. Based on current regulatory framework in Montana, disposal of saline waters is a difficult problem, and may be a significant deterent to widespread use of drainage systems.

Although there has been considerable work on understanding saline seep problems, there are few on-the-ground attmepts at solution or abatement. Most solutions require less profitable crops and consequently there is a reluctance to change farming practices. Saline seep probably will increase as additional land is converted to cropland. Also, in many areas, saline seep problems are being created, but are not visible as yet. These will become problems in future years. Saline seep will continue to be the major source of groundwater pollution in Montana for many years to come. Much additional work is needed particularly to understand the broad hydrologic implications of saline seep and to develop deomonstrating areas showing successful solutions. Widespread on-the-ground solutions must be implemented to abate this problem.

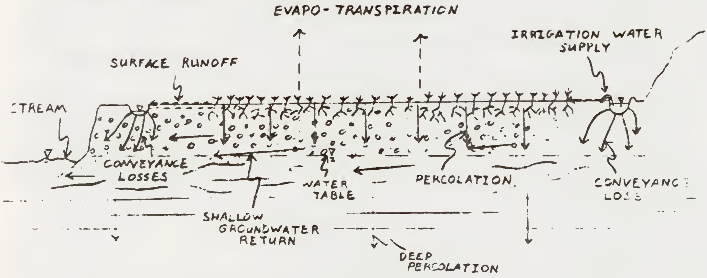


Figure 16 Hydrologic balance of a flood irrigation system.

If excess water is suppled it will infiltrate below the root zone and a major portion of this deep percolation will gradually return to the surface water system by subsurface movement. It is the subsurface portion of the irrigation return flow that is important in groundwater quality. If the amount of water applied to the ground surface is insufficient to carry the accumulation of salts away from the root zone, the soil will eventually become saline and will be unsuitable for crop production. If sufficient water is applied to the soil to remove salts from the root zone, groundwater may increase in salinity and may become unusable for human, livestock, and irrigation uses. If too much water is applied to the soil, irrigation water may be wasted; water tables may rise, and unnecessary leaching of salts from subsoils may occur.

There is little quantitative data available on impacts of irrigation on groundwater quality. In a water efficient irrigation system, about 80 percent of percolating water is lost to evapotranspiration with the remaining 20 percent entering into the groundwater system. Water that enters the groundwater system, however, contains 100 percent of the original salt load increasing the concentration of salt in the water by 500 percent. If crop requirements are 30 inches per year, 20 percent, or 6 inches of water, enters the groundwater with a salt concentration five times that of the applied surface water. Whether groundwater is degraded in quality in any particular area depends on the original quality of the groundwater. Unfortunately, very little data is available on groundwater before irrigation projects have commenced. (Ray Choriki, pers. comm., 1977).

Presently there is little incentive for irrigators to conserve water. Actually, the reverse is true for those operators concerned with maintaining a water right. It has been found that many irrigators have been using excessive water,

far in excess of crop requirements. A commonly used figure in irrigation feasibility studies is a diversion of 5 acre-feet per acre (typical crop need is 2-3 acre-feet/acre) annually with a return of 2 acre-feet/acre to streams where it is available to downstream irrigators (DNR&C, 1975). This implies that irrigation returns travel relatively fast by surface and/or subsurface flows.

Quality of water can be influenced by the date of diversion. A large portion of the surface waters are applied in June and July, when streamflows contain abundant rainfall and snowmelt and typically are higher in quality. If this high quality water is diverted from the conveyance system with a typical conveyance loss of 50 percent, and the remainder applied to crops in excess of crop requirements, a slug of relatively good quality water will enter the groundwater system. There will be some concentration of dissolved materials by evapotranspiration, however, the application of excess water to the field and conveyance losses may in fact cause a large amount of high quality water to enter the groundwater system. This early application could, depending on specific condtions, improve groundwater quality, and act as a buffer for later applications of poorer quality irrigation water. An alternative condition would be the sprinkler application of groundwaters of marginal quality for irrigation. By careful application with sprinkler systems to ensure no more water used than required, it is possible to have the salinity in the surface waters increased by a factor of 5 before it enters the groundwater system. In fact, if the soil were not flushed in a uniform manner year by year, it is possible that a buildup of salts could occur in some years. A flushout of all the accumulated salts could occur in other years yielding groundwater that was significantly poorer than the marginal quality water used as the irrigation water source.

The conclusion from these two application scenarios is that the impacts on groundwater can be highly variable and can range from improving to greatly decreasing the groundwater quality. To quantitatively determine impacts of irrigation on groundwater requires a soil, crop, and water specific investigation that considers quality of existing groundwater in the area, irrigation practice, drainage, and climate.

The plains portion of the Statewide 208 Area includes the Milk, Missouri, Musselshell, Teton, Marias and Lower Yellowstone Rivers. All but the lower Yellowstone drainage contain areas of glacial till commonly underlain by relatively impermeable shales and clays. Irrigation systems in these areas vary from individual pumping sites to large irrigation projects in excess of 10,000 acres in size. The soils and waters in these areas tend to be more saline than in the mountainous portions of Montana and the west. Irrigation in this area utilizes water of poor quality to irrigate land containing greater amounts of salinity, thus, increasing the potential for irrigation problems.

Relatively new to agriculture in Montana is the widespread use of sprinkler irrigation. Capital and energy intensive, these systems supply little, if any, more water than is required for crop production. Many areas that are poorly drained are being developed and it is estimated that 260,000 acres were irrigated by sprinklers in 1975 (Kaiser, Gorman, and Botz, 1976). With sprinkler irrigation, salts present in the irrigation waters are deposited in the soil profile or, if sufficient waters are applied, are leached below the root zone.

It is obvious that groundwater quality in the Statewide 208 Area can be changed by irrigation activity. The enormous amount of irrigation in Montana clearly represents a major factor relative to groundwater quality. To determine specific groundwater problems from irrigation activities in Montana, a number of persons were contacted including the U.S. Bureau of Reclamation, Montana State University, the Huntley Agricultural Experiment Station, and the Agricultural Experiment Station in Mocassin. No one had any definitive answers on the question of irrigation impacts to groundwater quality. Discussions with officials in North Dakota and Idaho indicated there is also little data concerning agricultural impacts on groundwater quality in those states. In a study of groundwater pollution problems in the northwestern United States (EPA, 1975), no case histories of groundwater problems in Montana, due to irrigation, have been cited.

In other states, however, there have been numerous studies that directly or indirectly approach the relationship between irrigation and groundwater quality. The movement of fertilizers, feedlots, and pesticides through soils under a wide range of water application rates has been investigated as a specific case in the middle South Platte River Valley, Colorado (Stewart, Viets, and Hutchinson, 1968). Average total nitrate-nitrogen to a depth of 20 feet was 1436 lb/acre under feedlots, 506 lb/acre under irrigated row crops, 261 lb/acre under dryland row crops, 90 lb/acre under native grassland, and 79 lb/acre under alfalfa. The average annual loss of N to groundwater under irrigated row crops was estimated at 25 to 30 lb/acre. Feedlots located near homesteads had much more effect on nitrate content of water from domestic wells than did cropped land.

If the same type of nitrogen loss occurred on irrigated lands in Montana and assuming an excess of one acre/foot of water was applied per acre annually, the concentration of nitrogen in that return water would be 9.2 to 11.0 mg/l N. The timing of water and fertilizer application would be critical in attempting to lower this concentration.

Irrigation wastewater impacts on groundwater was studied in Idaho (EPA, 1977) with respect to disposal wells. Drain wells are used to dispose of excess irrigation and surface runoff water from approximately 320,000 acres of agricultural land within the eastern Snake River Plain area of southern Idaho. The aquifer affected is the Snake Plain aquifer, primary water source for 140,000 people. This aquifer allows rapid lateral movement of groundwater through fractures and channels. Bacterial levels and turbidity within the recharge zone approached those of the discharged wastewater and were far in excess of drinking water standards (EPA, 1977).

Pesticides and trace metal concentrations in the irrigation wastewater were within Idaho drinking water standards. The chemical quality of wastewater with respect to common ions surpassed that of groundwater. Total and fecal coliform bacteria and sediment were the only contaminants found in irrigation wastewaters in excess of drinking water standards.

Deep percolation of injected wastewaters resulted in bacterial contamination of both the deep perched water zone overlying the confining layer, and the artesian groundwater system. Suspended solids, as measured by turbidity, were filtered out by the percolation process.

The highly permeable, fractured, condition of the Snake Plan aquifer is unusual in Montana. The movement of coliform bacteria would be severely retarded in most other types of soils, including highly permeable sandy soils.

A field study (White and Suneda, 1974) of the Severance groundwater basin, near Windsor, Colorado, looked at the combined effect on groundwater quality of:

(1) Leaching of applied fertilizer

(2) Drainage from silage pits and feedlots

(3) Percolation of contaminants from oil field brine pits

(4) Irrigation

(5) Geologic contamination of the aquifer

In this basin, total dissolved solids (TDS) had increased from 6100 mg/l to 700 mg/l between 1961 and 1965, a 200 mg/l per year increase. The investigators concluded that the major causes of contamination in this aquifer were the high rate of evapotranspiration and the relatively low surface and groundwater outflow from the basin. This results in a TDS increase of 170 mg/l per year.

The contribution of contaminating organic material from feedlots, silage pits, and fertilizers and brine pits, appeared to be relatively small. The evidence indicated further that the geologic formations are not currently contributing any major pollution load to the aquifer.

A final conclusion is the apparant substantiation that groundwater contamination in semi-arid and arid agricultural regions subjected to irrigation is due to high evapotranspiration rates. The salt load added each year, due to irrigation, was polluting the groundwater in the Severance Basin.

Of particular concern to investigators has been the movement and loss of nitrogen. Since this segment of crop production is expensive for the producer and has a considerable potential for groundwater pollution, there has been incentive to attack this problem. Extensive investigation has

been completed by Wendt, Onken, and Wilke (1976), Stewart et.al., (1967), and Viets and Hageman (1971).

The investigations cited lead to an overall conclusion that the impact of irrigation on groundwater quality is highly variable and specific to site, operator, applied water quality and quantity, natural groundwater quality, and fertilizer, pesticide, and water application techniques.

The relationship of applied irrigation water quality to the quality of groundwater receiving the return flow is particularly critical. Where surface waters are of better quality than groundwater, irrigation with those waters can be accomplished, with appropriate techniques, without degradation of groundwater quality. An exception to this generalization would be those areas naturally susceptible to saline seep problems.

In those areas where surface water quality is poorer than groundwater quality, application of these waters for irrigation will always cause degradation of groundwater quality.

Of major concern is the increase in groundwater usage for irrigation. Typically, these irrigation systems use sprinkler equipment and application rates are carefully controlled to minimize water and energy use. This may cause a five or six-fold increase in salt concentrations in return flow to the groundwater system. It is obvious that it is only a matter of time before the aquifer being used for irrigation water supply will be seriously degraded for that use, unless the pumped aquifer is hydraulically separated from the return flows.

The complex relationship between applied surface waters and eventual potential for degradation of groundwater quality due to irrigation return flows is beyond the scope of this report. In fact, no one has definately answered these questions. It appears that water quality problems due to irrigation

can only be handled on a case-by-case basis. It is highly probable, with the large acreages of irrigated land, and the variety of operating techniques used, that there are a number of cases where groundwater quality has been seriously degraded. However, no irrigation system in the Statewide 208 Area has been recognized as having adversely impacted groundwater quality sufficiently to warrant detailed investigation.

Fertilizers

Fertilizers include any organic and chemical substances that provide enhanced growing conditions for plants. Organic fertilizers include animal manure, crop residues, organic debris and green manure (plowed under grasses and weeds). These fertilizers decompose gradually providing a slow release of nutrients as well as helping to improve soil structure. Chemical fertilizers are manufactured to provide specific nutrients such as potassium, nitrogen and phosphorus. Also included as fertilizers in this report are chemical amendments for soil conditions such as gypsum and sulfuric acid, used to change soil texture or pH. In Montana, approximately 85,000 tons of primary nutrients (nitrogen, phosphate and potassium) are used annually on about nine million acres of harvested cropland (USDA, 1977). Nitrogen (as nitrate) has the most potential of all fertilizers for reaching groundwater systems. Phosphorus fertilizers are applied in greater tonnages (USDA, 1970), but tend to adhere to soil particles long enough to be used by plants. Potassium salts are very soluble but aren't applied in as large quantitites as nitrogen fertilizers. The mechanism whereby fertilizers can degrade groundwater quality is by solution of the fertilizer chemical in infiltrating water and downward movement into groundwater systems.

Organic fertilizers also are widely used in Montana including an estimated 7,000 tons of nitrate per year in animal manure (Montana Testing Labs, 1977).

Organic fertilizers tend to reduce leaching by absorbing or storing excess moisture and by slow decomposition.

Potential for groundwater quality degradation due to fertilizer applications depends on management. Studies on dryland, wheat-fallow rotation, have noted leaching of nitrate below root zones (below 6-7 feet) (Jim Simms, pers. comm., 1978). According to Simms, when the nitrate to water ratio was optimum for plant growth, no downward leaching of nitrate was noted. Deviation from the optimum produces downward movement of nitrogen not only in applying too much fertilizer but also in applying too little fertilizer.

Nitrogen movement as a result of flood irrigation was examined in the Ronan-Kalispell area (Graham, pers. comm., 1978). Soils were sampled to depths of 12 feet on sites estimated likely to have groundwater problems. About 18,000 samples were analyzed in an area predominatly used for potato production and where excessive irrigation is rather common. Results of this investigation are inconclusive but has not shown contamination in deep wells. Phosphates were retained within the soils and orthphosphate was found in the three-to-four-foot zone below ground surface, but no proof of further downward movement was discovered.

Use of fertilizers in Montana in 1955 to 1976 (Figure 17) shows a greatly increased use of nitrogen and phosphorus fertilizers. Total use of fertilizer material increased by 964 percent between 1955 and 1976 (Montana Dept. of Ag., 1976). There have been numerous investigations of nitrates and phosphates in groundwaters. Excess levels of nitrate in groundwaters from fertilizer applications have been described by Peele and Gillinghan, (1972), Larson and Henely (1966) and Murphy and Gosch (1970). The South Platte Valley of Colorado study by Stewart, Viets, and Hutchinson (1968) found that up to 25 to 30 pounds of nitrogen per acre were lost annually to the groundwater.

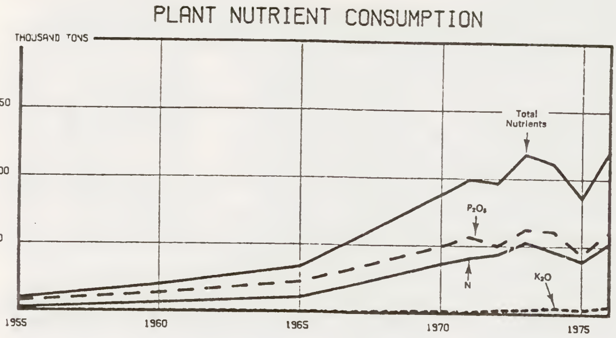


Figure 17. Historical trend in fertilizer use in Montana
Source: Montana Dept. of Agriculture, 1976

A study of the impact on groundwater quality due to well disposal of irrigation wastewaters in Idaho (Graham, Clapp, and Putkey, 1977) showed that nutrient concentrations in those wastewaters were within Idaho drinking water standards.

Pesticides

Pesticides are chemical, physical, or biological agents designed to kill insects, rodents, weeds and fungi. Pesticide commonly is used as an overall name to include insecticides, herbicides, rodenticides, fungicides, disinfectants and sanitizers. In Montana, based on data from the U.S. Department of Agriculture (1969), 2,900,000 acres were sprayed for weeds in crops; 87,000 acres were sprayed for weeds in pasture; and 323,000 acres were sprayed for insects. A survey in Montana by Walther (1972) indicated that in 1971 more than 1,637,000 pounds of pesticides and 190,900 gallons of pesticide were sold. The majority of these were organic phosphates, herbicides and growth regulators and fungicides. Most of these pesticides are water soluble, are primarily used in agricultural activities, and are applied over large areas. There are a large number of pesticides in use, many of which are complex, organic compounds that are difficult to detect and analyze. Walther (1972) describes the expenditure by state agencies as follows:

> The total monies expended in 1971 for these activities amounted to more than $330,000. The Department of Highways expended $129,000 for weed control. Approximately 49 percent of the total monies were expended for pest extermination and application of pesticides, 19 percent for research and investigation, 30 percent for education, and about 2 percent for the administration of the state regulatory agency.

Pesticides are used nearly everywhere including forests, cropland, rangeland, farms and gardens. Majority of usage is in the agricultural industry particularly herbicide use. Many pesticides rapidly decompose, but some are persistent, particularly the chlorinated hydrocarbons. Pesticides also

are known to be absorbed in soils to varying degrees. Widespread use of pesticides, particularly on agricultural land, where irrigation often follow pesticide applications, involve a possible threat to groundwater quality. In addition to pesticides application, the handling, storage, and disposal of pesticides can cause localized groundwater pollution if spills occur. It also should be noted that small grain crops not only involve pesticide use in a normal crop fallow situation, but can lead to infiltration of water into underlying groundwater systems due to the greater infiltration capacity of fallow land.

In Montana little research has been done to specifically examine groundwater impacts from pesticides and little is known concerning the overall past, present, or future potential of waste pollution from pesticides. In the northeast United States, a few examples of pesticide contamination of groundwater have been noted (EPA, 1974). These groundwater problems are, however, very local and specific in nature, and should have little transfer value. In the northwestern United States, most cases of groundwater contamination of pesticides are those resulting from accidental spills in the vicinity of wells or into irrigation canals with subsequent leakage into groundwater (EPA, 1975). This EPA report further describes Canyon County in southern Idaho where large quantities of pesticides are used and concludes that no documented cases of groundwater contamination have been reported, however, there was no description of the data that led to this conclusion. Studies by McCarty and King (1966) have shown that fine-grained soils will absorb pesticides and that absorption and degradation affects in soils must be considered in predicting leachability and movement of pesticides to groundwater systems. Other studies, such as those by Eye (1968) and Robertson and Kahn (1969) have shown substantial absorbtion of chlorinated hydrocarbons in coarse earth materials. Examination of movement of 2,4-D in soils

indicated 2,4-D leaching was found to be dependent on soil permeability (Dregne, 1969) and Mansell and Hammond (1971) determined that transport of 2,4-D is absorbed in a mucky peat and in fine sands.

In Montana there have been reported spills of pesticides in the Bridger area at two locations where pesticides were back siphoned into wells and in the Great Falls area (Kit Walther, pers. comm., 1978). These incidences have not been investigated and appear to be localized problems. The overall impact of pesticide usage in Montana on groundwater quality is unknown and no past or existing investigations are available that examine the relationships between this potential pollutant and groundwater systems.

Feedlots

The number of cattle fed in Montana varies considerably depending on market conditions and season. In recent years the number of animals in feedlots varied from 62,000 in 1976 to 130,000 in 1973 (Montana Crop Reporting Service, 1975). Livestock in feedlots generate large amounts of solid and liquid wastes; each animal produces the waste equivalent of approximately six people. Steers in feedlots excrete approximately 0.4 pounds of nitrogen per day (Montana Testing Labs, 1977). Thus, there is a definite potential for nitrogen contamination of groundwaters present beneath feedlots. There are 175 feedlots under permit in Montana that are continuously operated (S. Pilcher, pers. comm., 1978).

In an investigation of feedlots 5 to 15 years old, Montana Testing Labs (1977) determined that nitrate concentrations under feedlots were similar to well fertilized irrigated cropland. It was also determined that feedlots used intermittently have six times the nitrates in the subsurface soils as those used continuously. The increase of nitrates in intermittently used feedlots is thought to be due to nitrification during summer months as feedlots

lay idle. Summer rains, warm temperatures, and lack of continual compaction encourage oxidation and resulting high rates of nitrification. If cattle are present in significant numbers, feedlot conditions consisting of continuous manuring and trampling is thought to cause packing of the soils, sealing of the feedlot surface and reducing infiltration of precipitation.

Numerous studies have been done on specific animal waste pollution problems. Stewart (1967) determined that high concentrations of nitrate were present beneath feedlots and data revealed that nitrate was moving into groundwater supplies beneath feedlots. An investigation in Nebraska (Mielke, 1970) determined that movement of nitrates downward in soil was a minor problem beneath feedlots located in a high watertable area along the Platte River Valley. Numerous studies of livestock feedlots have shown in some instances, downward migration of nitrogen and other compounds while, in other cases, nitrogen movement was severely limited due to low soil permeability. compacted soil, depth to water and subsurface and surface geological conditions. There have been no detailed studies of feedlot impacts on groundwater quality in Montana. Proper location, operation and management of feedlots can be significant in prevention of groundwater problems due to percolation of feedlot wastes.

Forest Products

Timber is an important natural resource in Montana and forest products are a major factor in the state's economy. The forest products industry includes logging, lumber production, wood products (plywood, fiberboard, laminated beams), post and poles, paper products and allied industries. This industry has both liquid and solid wastes and in the past few years, more restrictive air quality regulations in Montana have inhibited burning of wood wastes and made alternative means of disposal more attractive. This has led to some disposal on the ground surface and in landfills. Some segments of the forest product industry have the potential for interacting with groundwater and problems have occurred in groundwater in Montana from this industry. Montana has provided 3½ to 4 percent of the total soft wood lumber consumed in the Unites States (US Forest Service, 1975).

Wood wastes, including paper product wastes, contain tannins, lignins, wood sugars, sulfates, sulfites, and calcium compounds. The tannins and lignins are hydroxylated aromatic compounds (phenol) derivatives and produce odors, color, and tastes in water.

Logging

Sawmills are scattered throughout Montana, but are present primarily in the timber rich areas of the state west of the Continental Divide. An area of major lumber production is in the northwestern portion of the state and sawlogs come principally from six western counties (Selser, 197[illegible]). There were an estimated 120-215 sawmills in Montana as of 1973 (US Forest Service, 1975). At the larger sawmills, it is common to have a substantial volume of stacked logs that require watering to prevent spontaneous combustion and for disease control. Liquid effluent from these logs contains organic

chemicals that cause taste, color, and odors. These effluents can seep into the ground and cause groundwater pollution problems. A problem of this type was investigated at a woods products plant near Bonner, Montana (Botz, 1975). At this operation, excess water from log spraying was combined with some water from the mill creating a waste with a distinct odor and a dark color. This water was temporarily ponded on the property which was underlain by permeable sands and gravels and had a relatively shallow water table. Infiltration of the waste caused problems with odor and taste in domestic water wells located near the ponded effluent. Chemical tests for tannins and lignins showed that several wells in the area had measurable quantities of tannins and lignins, as did the water in the plant storage pond. Corrective steps were taken by the industry to improve their operation and they worked with the community on improvement of the water supply.

It is expected that areas of substantial log storage that are sprinkled could lead to runoff water and could cause infiltration and subsequent changes in quality of groundwater in the area. Although there were nine companies producing in excess of 50 million board feet of lumber per year in 1975 (US Forest Service, 1975), problems of groundwater pollution have not been identified at any of these operations.

Important factors in possible groundwater pollution from log sprinkling would be amount of runoff water generated, soils underlying the area, depth to groundwater and geologic materials in and above the groundwater. Some earth materials can efficienty remove color from wood wastes and also may remove tannins and lignins.

In recent years, more restrictive air quality regulations have caused many tepee burners to be modified or eliminated. These burners were the primary method for disposal of sawmill wood wastes. In response to the more restrictive burning requirements, alternate disposal methods have been developed including providing wood chips to a pulp plant and land disposal. Burial and land disposal of wood wastes has been noted along the Clark Fork River in northwestern Montana and is probably occurring in other areas. No groundwater problems have been noted from wood waste disposal in the Statewide 208 area. However, such problems have occurred in the Kalispell area. In the community of Evergreen near Kalispell, a large volume of wood wastes were disposed onto the land (W.Aikin, Water Quality Bureau, pers. comm., November, 1977). Leachates from these wastes created odor and color problems in nearby domestic water wells.

In any area where sawmill wastes or other wood wastes are used for landfill or are spread over the ground surface, a groundwater quality problem could occur. Leachates from infiltration of precipitation would contain organic pollutants that could cause color, taste and odor problems in groundwater.

Poles and Posts

Poles and posts including transmission poles, fence posts and corral poles are produced at a number of locations in Montana. The only potential ground-water problem that could occur from production of these wood products would be from disposal of the wood wastes, or loss of creosote or other preservatives. Production of poles and posts typically is done by debarking and trimming which results in waste.

If sufficient wood wastes were generated, a leaching could occur into groundwater systems. There have been no problems of this type identified in the Statewide 208 area in Montana, but little, if any, work has been done investigating post and pole plant sites. Preservatives are widely used in post and pole treatment and are generally toxic liquids that could create groundwater pollution problems if spilled. Such problems have not been identified to date.

Plywood and Fiberboard

There are a number of plywood and fiberboard producing plants in Montana including U.S. Plywood at Bonner, Louisiana Pacific and Intermountain Lumber, Evans in Missoula, Plum Creek Lumber in Columbia Falls and St. Regis Lumber in Libby. Liquid wastes are developed from these plants and from adhesive used in these facilities. These liquid wastes typically contain odor and taste producing compounds and are colored. Without proper disposal, these wastes can lead to groundwater problems. There have been, however, no groundwater problems identified with these facilities in Montana.

An associated facility of fiberboard and plywood production is the production of glue. The Borden facility in Missoula produces glue for use in wood products. Glue production involves toxic organic chemicals that could create taste and odor problems in groundwater. However, problems of this type have not been identified in Montana.

Paper Products

The only paper plant in Montana is the Hoemer-Waldorf plant in Missoula, Montana. This is a large Kraft-paper manufacturing plant located several miles downstream from Missoula, Montana. As part of this process there are large areas of lagoons containing process wastewater.

A total of approximately 750 acres of storage and seepage ponds are present at the Horner-Waldorf site as of 1974 (Montana Department of Health and Environmental Sciences, 1974). Material in these ponds is from the 15.8 mgd (millions of gallons per day) of liquid wastes from the plant. The major source of organic wastes is from the pulp washing operation, evaporator condensates, and spills and overflows. Principal source of color in the water is from the bleaching operation. The majority of the effluent percolates through the ground to the adjacent Clark Fork River. This has created a groundwater body under and peripheral to the storage ponds that contains odor, taste and color producing organic compounds. This waste water appears to be primarily confined to the shallower aquifer in the area and there have been no substantiated cases of groundwater quality degredation peripheral to the Hoerner-Waldorf property (Department of Health and Environmental Sciences, EIS, 1974).

Recent discussions with Hoerner-Waldorf personnel (Larry Weeks, pers. comm., 1977), indicate that approximately 550 acres presently are being used for infiltration and that a rapid infiltration system is being used on approximately 88 acres for disposal of liquid wastes.

Mining and Mineral Processing

There is substantial mining and mineral processing in the Statewide 208 Area. There are 36 minerals that occur in commercially important quantities; 25 have been mined in the past or are mined today, and it is expected that there will be significant increases in production in the future for some of these commodities (Schmidt and Botz, 1978). There are 64 hard rock operating permits, 927 small miners, 269 sand and gravel operations, and 9 coal mining operations in Montana. The vast majority of these operations are in the 42-county Statewide 208 Study Area. There are seven mineral concentrating facilities in the Statewide 208 Area, eight leaching operations, five refining facilities, many operations involving crushing, washing, and sorting, and, there are many tailings and waste dumps.

Mining

Mining in Montana includes placer mining, underground hard rock mining, bentonite, phosphate, sand and gravel, and many other types. The relationship of mining and water quality has been examined by Schmidt and Botz (1978), and they described both impacts on groundwater and surface water in the Statewide 208 Area. In many mining operations, pyritic materials are encountered which, when combined with oxygen and water, will yield acid waters. There are many acid mine drainage problems in the Statewide 208 Area, and these problems can be considered groundwater pollution problems. The relationship of acid mine drainage and water pollution has been described by Schmidt and Botz (1978), and they conclude that hard rock mining of sulfide-bearing materials and coal mining in the Belt/Sand Coulee area, has caused numerous problems of acid mine drainage. Acid mine drainage as it exits the mines typically flows to the nearest stream. Groundwaters in an area of acid mine drainage become polluted with acid waters and metals.

This type of groundwater pollution generally is localized near the mines, in the underground workings of mines, and beneath and adjacent to streams that are impacted by acid mine drainage.

Other groundwater problems associated with mining include discharge of nonacid wastes from mines. These types of waters generally do not create as severe a problem as those associated with acid drainage. Common pollutants associated with this type of mining are nitrogen due to blasting, dissolution of specific commodities such as gypsum, fluoride, and iron which can cause localized groundwater pollution. In the Statewide 208 Area no problems of this type are known, however, there have been few detailed investigations of these types of mines.

Groundwater often is encountered in placer mining, in sand and gravel operations, and at bentonite mines. Generally there is little groundwater impact from this type of mining and no examples of significant groundwater pollution are known to be associated with these activities in the Statewide 208 Area.

Another potential source of groundwater pollution associated with any type of mining would be losses of hazardous or toxic materials associated with the mining operation. This would include such things as antifreeze, gasoline, diesel fuel, other petroleum products, and chemical reagents. Good operating practices would prevent pollution from these sources and no groundwater pollution from such materials is known in the Statewide 208 Area.

Mineral Processing

Associated with the mining industry are a variety of mineral processing activities including crushing, washing, sorting, concentrating, leaching, and refining. All these activities occur to some extent in the Statewide 208 Area, and nearly all of these mineral processing steps have to dispose of waste or tailings material.

Mineral production activities such as barite, silica, bentonite, sand and gravel, and placer mines all include either crushing, washing, or sorting as part of the process. All these steps are mechanical and they involve separation of the ore material from waste or a reduction in particle size. In any of these operations, particularly those involving washing and sorting, there is an opportunity for water to enter the groundwater system. Most of these activities, however, cause little chemical or physical change in water except for an increase in turbidity, thus, infiltration has minimal impact on underground water systems. In the Statewide 208 Area, crushing, sorting, and washing operations are not known to have caused any impacts on groundwater.

Concentration

Within the Statewide 208 Area, there are seven concentrating facilities that take ore and, by a chemical or a combination of chemical and physical processes, increase the concentration of specified minerals in the concentrate and leave a relatively barren waste. Concentrating facilities in the Statewide 208 Area include the Red Pine flotation mill where base metals (primarily gold) are separated by a flotation process; the Anaconda Company concentrator in Butte, which produces a copper concentrate by froth-flotation; and a 350 ton/day antimony concentration facility at the Babbit Mine near Thompson Falls; a 250 ton/day gold flotation-cyanide mill in the Rochester mining district; a tungsten mill at Silver Lake; a gold stamp mill located west of Townsend; and a 100 ton/day flotation-cyanide mill near Virginia City.

The mineral concentration steps are all contained and hydraulically well regulated and usually housed in a mill facility. A major problem associated

with concentrating facilities is disposal of waste material from the concentrator. This is discussed in the section on tailings and waste materials. In concentrating operations, chemicals are used to assist in flotation and froth development. In any concentrating facility, chemicals must be stored and handled to prevent spillage and possible seepage into groundwater. These chemicals are expensive and are usually handled carefully to avoid such losses. If losses do occur they are normally within an enclosed facility and can be cleaned up. There are no known water quality problems in the Statewide 208 Area from concentrators.

Leaching and Solution Mining

There are a number of leaching operations occurring in the Statewide 208 Area including both cyanide leaching of gold and silver-bearing ores and acid leaching of copper ores. The acid leach operation at the Anaconda Company in Butte involves injection of an aqueous solution of sulfuric acid into a low-grade copper leach dump. The solution percolates through the leach dumps, dissolves copper, and exits onto prepared pads and into a collection system. Pregnant leach solutions are collected at the base of the leach dumps and diverted directly to a refining operation which consists of shredded iron and steel in long troughs. Due to the elctropotential difference between copper and iron, copper is deposited in the troughs and iron goes into solution. This results in a high-grade copper sludge that is recovered for further refining. This acid-leach operation covers a large area north and northeast of the Berkeley Pit (east of uptown Butte).

As the dumps are leached, the grade of the pregnant solution declines until it is no longer economical to continue the leach operation. Copper leaching has been conducted for many years at the Butte operation, and there are

many acres of leach dumps that have been exhausted. There has been some examination of groundwaters in the vicinity of these leaching dumps and there is some movement of leach solutions underground. There are, however, several leach dumps that have been investigated and it was shown that copper leach solutions have not significantly penetrated soils beneath the dumps. Leach dumps are constructed by either laying an asphalt pad or constructing a compacted earth pad. Coarse run-of-the-pit rock is placed on the pads and during the dump operation there is a natural segregation of the rock with larger pieces going to the bottom of the dump. This forms a natural underdrain at the bottom of the dump and gives a permeable path for leach solutions to exit the dump.

In the Anaconda leach dump, the Berkeley Pit acts as a large groundwater drain, thereby, restricting movement of leach solutions that may penetrate the ground. This has confined the area of groundwater impacted by leach operations to a zone between the leach dumps and the Berkeley Pit. There have been no known cases of groundwater pollution outside of this area due to leach operations.

There are a large number of cyanide leach operations that are either in operation, are proposed, or have recently operated in the Statewide 208 Area. Cyanide is used to recover silver and gold from low-grade ores. Cyanide leach operations have been conducted near Whitehall, on Silver Creek near Helena, near Virginia City, Philipsburg, and Butte. In addition, there are two proposed operations, one near Zortman and one near Elkhorn, Montana.

The first commercial application of cyanide leaching was to gold ores in 1887 to 1888. Since that time, the processs has been extended to silver ores and has become a standard operation with many major gold operations in the world. The process is adaptable to nearly all gold and silver ores,

while telluride ores and oxidized zinc and copper cause interferences. Gold and silver leaching is one of the major uses of cyanide in the world. Typical quantities of cyanide used by these operations ranges between 1,000,000 and 2,000,000 pounds of cyanide per year as sodium cyanide. Mining operations in the 11 western states use approximately 10,000,000 pounds of cyanide per year.

Most leaching operations use a mill for grinding and containers of some sort to process batches of ore. The host rock is a waste product from the mill after processing the ore. An increasingly popular use of cyanide for gold and silver production is the application of a dilute solution of sodium cyanide by spray. A pile or heap of ore is commonly placed on an impervious pad to prevent cyanide-bearing waters from entering the groundwater system. The leaching solution is applied to the ore pile, (termed leach heap) in the form of a spray similar to irrigation sprinkler systems. The cyanide solution comes into intimate contact with the ore and leaches gold and silver from the pile. As the cyanide solution passes over the rock particles, a number of reactions are possible. The desired result is the formation of gold and silver complexes as described by Peele (1941).

$$2Au + 4NACN + \tfrac{1}{2}O_2 + H_2O \rightarrow 2AuKa(CN)_2 + 2NAOH$$

$$2Ag + 4NACN + \tfrac{1}{2}O_2 \rightarrow {}^{2}AgKa(CN)_2 + 2NAOH$$

If silver sulfide is attacked, the reaction may be:

$$Ag2S + 5NaCN + \tfrac{1}{2}O_2 + H_2O \rightarrow NaCNS + 2NAOH$$

Variations in the above reactions are caused by the presence of base metals as sulfides or other salts, and by soluble salts of alkaline earths, always present in ores. Oxidized zinc and copper ores cause high consumption of cyanide due to ready solubility of their oxides, carbonates, and hydrates. Sulfides of copper, nickle, cobalt, lead, zinc, and iron react, but only

slightly, with cyanide solutions. Pyrrhotite (magnetic pyrite), though, tends to oxidize and act as a cyanacide. Certain copper sulfites, as chalcocite, cause increased cyanide consumption. The term cyanacide, as used above, refers to the destruction of cyanide capability to function as a leaching agent, not to its molecular decomposition. Soluble sulfides (expecially alkaline sulfides) interfere seriously, both by combination with cyanide and by reprecipitation of silver and gold. Since these complexes are soluble in a basic aqueous solution, they will tend to concentrate in a system that recirculates leaching waters (Peele, 1941).

If the leach heap and ponds are not adequately sealed, the circulating cyanide solutions can pollute groundwater. Solutions reaching groundwaters will become less basic and release a cyanide gas, which is toxic to humans and animals. The remaining cyanide either precipitates as metal complexes, adsorbs to soil particles, or remains in solution. Cyanide in groundwater solutions can be destroyed by oxidation with calcium hypochlorite (HTH), hydrogen peroxide, or chlorine. Table shows 0.05 mg/l cyanide will affect aquatic life and, for public water supplys, the cyanide concentration should be limited to 0.01 mg/l.

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Solution Mining

There are a few minerals that are readily soluble and can be mined by dissolving them underground then pumping the pregnant solutions to the surface. The process is termed "solution mining" and it has been used to produce uranium, sulfur, and potash. Solvents used are as varied as the mineral, but include alkaline and acid aqueous solutions, and steam. Solution mining is a relatively new technique for mineral production. Sulfur has been produced for years using hot water and steam to melt the product and force it to the well head. The advantages of solution mining are significant. Only a small area of land surface is necessary for wells, roads, and processing units. Aquifers other than the production zone, are left undisturbed except for exploratory and development holes which are drilled. With proper operation and plugging, aquifers should remain in their pre-mining condition. Overburden does not need to be removed nor do expensive underground workings need to be constructed.

Solution mining often allows the exploitation of mineral reserves that otherwise would not be economical. The disadvantages of solution mining techniques relate to the unknown characteristics of the mineral body. Since the proposed production zone is usually deep, extensive and expensive drilling must be done to discover and outline the economic ore zone. Each hole drilled must be cased or properly plugged to protect against interchange of aquifer waters. The production zone must have sufficient permeability to allow injected fluids to travel without excessive hindrance to collection wells. In areas of high permeability or complex geology, there is a possibility of loosing some injected fluids into the natural groundwater systems. Although there is no solution mining presently occurring in Montana, there are a number of firms that have applied for exploration permits to determine the feasibility of recovering known uranium reserves. To date,

all the significant activity has been in the southeast portion of Montana outside the Statewide 208 Area. Although there are several firms that may be ready to solution mine, there are no regulations from the State of Montana to control this activity and a moritorium on solution mining has been extended by the last Montana legislative session to allow for development of regulations. A description of solution mining techniques for uranium is included in the uranium section of this report.

Refining

From concentrating operations or in some cases, directly from the mine, most ores undergo a refining process. The cyanide leach operation generally includes a zinc precipitation or activated charcoal process for recovery of gold and silver. At most leaching operations the leaching and precipitation steps are handled in the same area producing a refined product. Acid leaching of copper ores produces a high grade copper sludge that is shipped to the Anaconda Reduction Works in Anaconda for further refining at the smelter, or to the Arbiter Reduction Works for production of copper anodes. Further refining of these anodes is done at the Anaconda Company, Great Falls operation, which produces electrical grade copper for transmission wire.

The ASARCO corporation smelter in East Helena, Montana produces lead bullion with traces of gold and silver, copper by-product, and zinc oxides. These are shipped to other ASARCO plants for further refining (Stan Lane, pers. comm., March 8, 1978). Sulfuric acid is produced as a by-product of the ASARCO refining process with a production capacity of 450 to 500 tons/day (Johns, 1976).

Another refinery operation is the 350 ton/day reduction furnace southwest of Thompson Falls that produces antimony of 99+ percent purity.

The Anaconda Arbiter Plant, which is a pilot facility, produces a refined copper product, but was reported to be shut down in the last year.

Although there are a number of refining operations in Montana, no problems of groundwater pollution are known from these mining operations. There have, however, been no detailed groundwater investigations at any of these refining facilities, thus, the status of groundwater quality in the vicinity of these plants is unknown. Other types of operations that process minerals include a cement plant at Trident, near the Missouri River; the Kaiser cement plant, on Prickley Pear Creek, near East Helena; and a facility near Missoula that drys, pulverizes and bags barite for the petroleum industry. No groundwater problems are known at any of these facilities.

Tailings and Waste Dumps

Tailings and waste disposal areas have created numbers of problems in the Statewide 208 Area. As described by Schmidt and Botz (1978), there are approximately 45 water quality problems that have been related to tailings or waste dumps. Generally, tailings are fine-grained and represent an erosional problem rather than a groundwater problem. However, in most tailings, there is some infiltration of groundwater through the tailings, and commonly there is groundwater exiting tailings and entering nearby stream systems. Another source of groundwater pollution in the Statewide 208 Area are waste dumps associated with mining operations. Nearly every mine has an associated waste dump, and water infiltrating into these waste dumps can create a body of polluted water that can enter into the groundwater system. Most waste dumps do not have any groundwater effluent and are located in dry areas where there have been no reported problems of groundwater pollution. Some waste dumps, however, are located near streams and have been shown to have water exiting these dumps.

Schmidt and Botz (1978) found erosion of tailings and waste dumps to be a significant problem impacting surface water quality. Acid mine drainage and erosion of tailings were found to be the most significant contributors to chemical water quality problems in the state. Important tailings related problems were found at: (1) Little Ben Mine, Phillips County, King Creek; (2) Bannack, Gold Leaf Mill, Beaverhead County, Grasshopper Creek; (3) McLaren Mill, Park County, Soda Butte Creek; (4) Heddelston mining district, Lewis and Clark County, Blackfoot River; and (5) Forest Rose Mine, Granite County, Dunkleberg Creek. The largest tailings ponds in the state are near Opportunity and are associated with the Anaconda smelting operation. The ponds near Warm Springs consist of the Opportunity ponds which extend from the Anaconda Company smelter, eastward to the Clark Fork River, and occupy an area of over 4000 acres. These ponds receive wastes from the Anaconda Company Reduction Works and the decant from these ponds goes to the Warm Springs pond system. No detailed investigations of these ponds have been made; however, it is thought that groundwater beneath and peripheral to the ponds is a calcium-sulfate type with small quantities of metals. Movement of water is eastward or northeastward toward the Clark Fork River.

The Warm Springs ponds occupy about 1600 acres along Silver Bow Creek. These ponds take the flow of Silver Bow Creek at the upper end and relase water to this creek at the lower end. The ponds significantly improve the quality of water in Silver Bow Creek.

Some seepage of metal-bearing waters occurs downstream from the middle pond in the system. These wastes are impounded in the lower pond and are returned to the middle pond. There has been no detailed investigation of groundwater conditions in the area, and the overall impact of these ponds

on groundwater quality is unknown; however, major groundwater pollution problems are thought to be present.

Waste dump erosion has caused a number of water quality problems, including: (1) The Crystal and Comet Mines, Jefferson County; (2) Hughesville mining district, Judith Basin County; and (3) Neihardt mining district, Cascade County.

Solid Waste

In Montana, nearly all domestic and municipal solid waste is placed in a designated refuse disposal area. This amounts to 4.28 pounds per capita per day, or 4.3 pounds per day for the Statewide 208 Area. Solid wastes are segregated relative to their potential toxicity and are grouped into three groups. These groups, as defined by the Montana Solid Waste Management Act, are Group I wastes which include hazardous wastes, toxic industrial chemicals, petroleum wastes, septic tank pumpage, and pesticide containers. Group II wastes include putrescible solid wastes, manure and other agricultural wastes, dead animals, combustible organics, infectious wastes from hospitals and medical facilities, and clean pesticide containers. Group III wastes include inert materials, such as brick, concrete, brush, demolition wastes, and industrial inert wastes.

Land disposal sites are put into three classes termed Class I, II, and III. Class I sites may accept Group I, II, and III wastes and must be situated where there is excellent protection of ground and surface waters. Class II sites are suitable for Group II and III wastes, and must be separated from existing groundwater by 10 to 20 feet and be underlain by low to moderate permeability soils. Class III sites may be disposed of in water-saturated areas, containing exposed groundwater.

In the Montana Statewide 208 Area, there are a total of 203 waste disposal sites, Nearly all of these are designed for Class II or Class III wastes. There are no Class I sites approved in the Montana Statewide 208 Area. Operation of landfills is controlled by the Solid Waste Management Bureau, which regulates siting and location of refuse disposal areas and classification of materials accepted at each of these areas. The dominant refuse at most disposal sites is normal community municipal wastes. There is an interest in

recycling wastes from refuse disposal areas and in the use of wastes for power generation. It is anticipated, however, that in the Statewide 208 Area in the foreseeable future, wastes will continue to be handled by landfill disposal with no major changes in disposal technique. Careful selection and operation of landfill disposal sites for solid wastes in Montana is a key factor in preventing groundwater pollution.

Sanitary landfills are designed to prevent nuisances or hazards to public health or safety. Potential pollution from sanitary landfills is a function of moisture that enters the landfill; its relationship to surface and groundwaters, and the nature of the refuse. The amount of water that enters a landfill depends on thickness and permeability of cover material, vegetation cover, the time it is exposed, and the precipitation.

Leachate quality is influenced by the composition and amount of refuse by its compaction. Typical landfill composition is shown in Table . Water which infiltrates into a refuse landfill will not appear as leachate until all refuse layers have reached field capacity (are saturated in moisture). In arid areas, net infiltration of water into a sanitary landfill may be zero, whereas, in areas of high precipitation, there may be an annual incremental increase in moisture entering the landfill. After a landfill reaches field capacity, it then can have leachate movement from the landfill downward to groundwater.

Impact of landfill leachates on groundwater was recently summarized by Brunner, D.R., and Keller, D.J.(1972):

> Solid waste deposited in a landfill degrade chemically and biologically to produce solid, liquid, and gaseous products. Ferrous and other metals are oxidized; organic and inorganic wastes are utilized by micro-organisms through aerobic and anaerobic synthesis. Liquid waste products of micro-biodegradation, such as organic acids, increase chemical activity within the fill. The food wastes degrade quite readily . . .

Table 1[illegible]. Typical Municipal Refuse Composition — U. S. East Coast

Physical	*Weight Percent*	*Rough Chemical*	*Weight Percent*
Cardboard	7	Moisture	28.0
Newspaper	14	Carbon	25.0
Miscellaneous paper	25	Hydrogen	3.3
Plastic film	2	Oxygen	21.1
Leather, molded plastics, rubber	2	Nitrogen	0.5
		Sulfur	0.1
Garbage	12	Glass, ceramics, etc	9.3
Grass and dirt	10	Metals	7.2
Textiles	3	Ash, other inerts	5.5
Wood	7		100.0
Glass, ceramics, stones	10		
Metallics	8		
	100		

Source: Apgar, M.A., and Langmuir, D.

Leachate from landfills has been shown to percolate downward to the existing groundwater table and to move with the underlying groundwater system. It has also been shown that interactions with soil and earth materials beneath landfills can be very important including cation and anion reactions on soil materials. The chemical character of landfill leachate has been described in many publications including (Dilaj and Lenard, 1975):

> . . . among the parameters of significant pollution qualities are pH, ranging from 3.7 to 8.5 and averaging 6.0; hardness, 200 to 7600 mg/l; alkalinity, 730 to 9500 mg/l; suspended solids, 13,000 to 26,000 and averaging 800 mg/l; COD, 800 to 50,000 and averaging 20,000 mg/l; chloride, 47 to 2350 mg/l; total nitrogen 200 to 450 mg/l; phosphate, 0.3 to 130 and averaging 20 mg/l; and sulfates, 20 to 730 and averaging 30 mg/l. In addition, zinc, iron, and other metals pose a problem.

In Montana, there have been two detailed investigations of groundwater pollution from sanitary landfills. One investigation was of the Livingston landfill by Botz, (1977), and the other was of the West Yellowstone landfill by Kringler, H. (1977). Results of these two investigations are briefly summarized to illustrate impact and character of groundwater pollution from sanitary landfills in Montana.

Livingston Landfill

The Livingston sanitary landfill is located approximately one mile northeast of the community of Livingston adjacent to the Yellowstone River and borders a flood channel of the Yellowstone River (Figure 18). The landfill has been in operation for about 12 years and handles normal solid waste from the community of Livingston. Portions of the landfill have been placed in the flood channel of the Yellowstone River and the landfill area is underlain by a shallow groundwater table, that in some areas, is contacting decomposible garbage. A portion of the landfill is actually beneath the groundwater table.

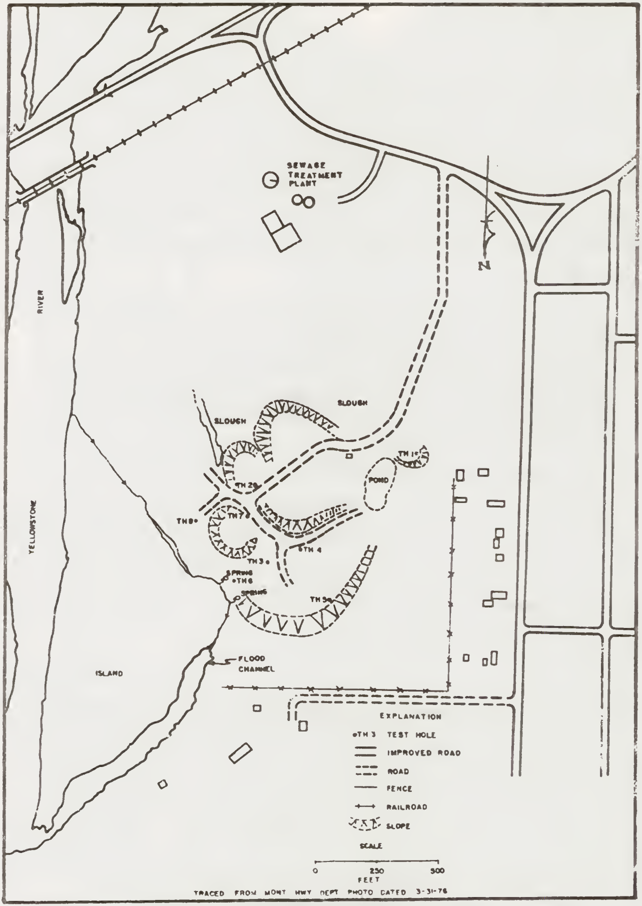


Figure 13. Plan map of Livingston landfill area.
Source: Botz, M.K., 1977

Geologically, the area consists of unconsolidated alluvial materials, primarily a sandy gravel that, in some ares, is overlain by a thin, sandy silty soil layer. Eight test holes were installed in the landfill to determine impacts of the landfill on groundwater.

There are numerous wells in the area that withdraw water for domestic use, stock, irrigation and municipal purposes. These wells are located primarily west and southwest of the landfill. Groundwater is present beneath the entire landfill site and this water body is part of a large aquifer that supplies wells in the area. Based on the data collected in the investigation, groundwater movement is toward the river.

There were substantial differences in water quality in the landfill and the groundwater quality was significantly impacted by leachate from the landfill. Water, as it passed through the landfill, was degraded and substantially increased in both organic and inorganic constituents. Parameters that showed significant increases were total dissolved solids, hardness, alkalinity, specific conductivity, chloride, potassium, total organic carbon, and chemical oxygen demand. Results of this investigation were consistent with results that have been obtained in other landfill investigations in other parts of the United States. This landfill, when saturated, does what other landfills of this type also do, that is, they create a body of polluted groundwater.

West Yellowstone Sanitary Landfill

This landfill is located on Forest Service land near the community of West Yellowstone, Montana and was open for use in 1971. Operation of the landfill has been excellent and in 1976, the State of Montana requested that all landfill sites be evaluated to ensure that they comply with current siting requirements. In the summer of 1976, the Soil Conservation Service drilled

two test holes near the landfill to determine water levels and to obtain groundwater samples. In August of 1977, the Forest Service and Conservation Service installed an additional nine test holes near the landfill site. Results of the groundwater monitoring showed that there was an increase in concentration of total dissolved solids, specific conductivity, carbon dioxide, iron, manganese, chemical oxygen demand and lead. It was concluded by the U.S. Forest Service (1977) that leachate from the landfill had reached the groundwater and was moving toward the Madison River.

The Solid Waste Management Bureau of the Montana Department of Environmental Health and Sciences, examined the water pollution potential for 36 solid waste disposal sites within the Statewide 208 Area. The sites were selected that served a population of over 3,000, or are sites that the Bureau felt had a potential of contributing to surface or groundwater pollution. All sites examined were for Group II or Group III waste with possibly some Group I wastes included at selected sites. The following list summarizes the results of this investigation:

Community	Groundwater Pollution Problems
Alder	Groundwater pollution during spring runoff and high seasonal groundwater. No control of septic tank pumpings or hazardous wastes
Anaconda	Infiltration of runoff and formation of leachate
Butte	Slight pollution potential from infiltration of runoff
Cascade	Possible long-term groundwater pollution problem due to infiltration of precipitation
Choteau	Slight potential for groundwater pollution due to infiltration of precipitation
Conrad	Minor pollution potential due to infiltration of precipitation
Cutbank	Very low potential for pollution
Darby	Pollution potential possibly high due to creation of leachates

Deer Lodge	Very low possibility of pollution
Dillon	Slight potential for pollution
E. Helena	Very low potential for leachate production
Eureka	Low to moderate pollution potential from leachate/groundwater contact
Fresno	Intense use of pesticides in this area may lead to disposal in the Havre sanitary landfill which is in the Havre water supply basin. Pollution potential high enough to recommend closing or relocating the site
Glasgow	Low pollution potential, but additional studies needed
Gt. Falls	Some pollution potential due to infiltration of precipitation and creation of leachate
Havre	Low pollution potential
Helena	Low to moderate pollution potential
Helena (scratch gravel site)	Low pollution potential
Lewistown (Harfort)	Low pollution potential
Lewistown (Mintyala)	Low pollution potential
Libby	Low pollution potential
Lima	High pollution potential due to infiltration and high water levels
Livingston	High pollution potential
Lozeau	Low to moderate pollution potential
Missoula (city disposal)	Low potential
Plentywood	Low pollution potential
Sand Coulee	High pollution potential
Shelby	Low pollution potential
Sheridan	High pollution potential due to high seasonal groundwater
Sidney	Low pollution potential

Stanford	High pollution potential due to high groundwater
Ulm	Uncertain pollution potential
Victor	Moderate to high due to infiltration of precipitation
Wolf Point	Low potential

The two landfills that have undergone detailed investigations have shown chemical contamination of underlying groundwater. Based on the Solid Waste Management Bureau analysis of Montana communities that have potential water quality problems, additional groundwater pollution is likely from sanitary landfills in the Statewide 208 Area.

Sanitary Waste Disposal

In the Statewide 208 Area there are 20 sewage treatment plants, 102 sewage treatment lagoons, 5 land disposal systems, and a few community septic tanks. There is no accurate estimate of the number of individual septic tank treatment systems with the Study Area. Many older waste disposal systems used cesspools and seepage pits which are now seldom used. There are few, if any, instances of disposal of raw sewage onto the land surface or into groundwater systems. With the increase in population of Montana, and with increasing emphasis on clean streams, there has been an added emphasis on use of septic tank disposal systems and on land disposal of domestic wastes. Currently in Montana, the Subdivision Bureau and the Water Quality Bureau are recommending land disposal of wastes associated with new developments and the new proposed Department of Health and Environmental Sciences Water Quality Standards direct land disposal systems to be used rather than disposal to streams.

The use of sanitary waste disposal facilities and, in particular, of on-site subsurface absorption systems are a significant part of the public health and sanitation program in the Statewide 208 Area. Feasibility of these systems and the reliability and degree of purification of both land disposal and subsurface absorption systems have been shown to be equivalent and often better than advance waste treatment systems.

There are several concerns in disposal of sanitary wastes. These include nitrogenous compounds, micro-organisms, increased total dissolved solids, organic compounds, and metals. A great deal of information has been developed relative to the physical and chemical composition of sewage. Table 12 shows the general compostion of secondary effluent which would be typical of wastes in municipal treatment systems. Of particular concern in groundwater

TABLE 12 TYPICAL COMPOSITION OF DOMESTIC SEWAGE
(All values except settleable solids are expressed in mg/liter)

Constituent	Concentration		
	Strong	Medium	Weak
Solids, total	1,200	700	350
Dissolved, total	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended, total	350	200	100
Fixed	75	50	30
Volatile	275	150	70
Settleable solids, (ml/liter)	20	10	5
Biochemical oxygen demand, 5-day, 20°C (BOD_5-20°)	300	200	100
Total organic carbon (TOC)	300	200	100
Chemical oxygen demand (COD)	1,000	500	250
Nitrogen, (total as N)	85	40	20
Organic	35	15	8
Free ammonia	50	25	12
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	20	10	6
Organic	5	3	2
Inorganic	15	7	4
Chlorides*	100	50	30
Alkalinity (as $CaCO_3$)*	200	100	50
Grease	150	100	50

*Values should be increased by amount in carriage water.

Source: Metcalf and Eddy, Inc., 1972

TABLE 13 NORMAL RANGE OF MINERAL PICKUP IN DOMESTIC SEWAGE

Mineral	Mineral Range (mg/l)
Dissolved Solids	100-300
Boron (B)	0.1-0.4
Sodium (Na)	40-70
Potassium (K)	7-15
Magnesium (Mg)	3-6
Calcium (Ca)	6-16
Total Nitrogen (N)	20-40
Phosphate (PO_4)	20-40
Sulfate (SO_4)	15-30
Chloride (Cl)	20-50
Alkalinity (as $CaCO_3$)	100-150

Source: EPA, 1975

and the major focus of interest in technical investigations, has been the movement and presence of nitrogen compounds and micro-organisms.

Bacteria and virus have been studied extensively in groundwater systems because of their abundance in sanitary wastes. Viruses are very small particles characterized by their inability to reproduce outside a living cell. They are much smaller than bacteria and are more mobile in groun-water systems. Bacteria, in particular those of the coliform group, are widely used as indicators of biological contamination, and are present in abundance in sanitary wastes. The earth has been recognized as a excellent filter for virus and bacteria and a number of investigations have been conducted to determine the "safe distances" between wells and waste-water disposal sytems. A key factor in this safe distance is the movement of virus and bacteria through porous materials. Romero (1970) summarized information relative to bacteria and virus movement in porous media, and he concluded that bacteria and viruses flow with groundwater and are rapidly removed by porous media. The rate of removal is a function of the aquifer characteristics, particularly median particle size; fine-grained materials tend to cause a much higher removal than do coarse-grained materials. Most bacteriological pollutants are filtered out in the first few feet of travel and seldom travel more than 50 to 100 feet from the point of origin. Further conclusions by Romero were: that pollution travel in unsaturated groundwater systems is limited to less than 10 feet; and that bacteria and viruses can survive in groundwater for substantial periods of time, particularly if nutrient-laden waters are intercepted. These conclusions substantiate earlier work on movement of micro-organisms in the soil showing that the soil system, particularly fine-grained soils, provide excellent mechanical filtration of micro-organisms in groundwater systems. Even in

coarse soils there is significant micro-organism removal (Merrell, Katko, and Pitler, 1964).

Literature relative to micro-organism movement clearly shows they are not a pollution threat to groundwater quality in porous materials that have a reasonably fine-grained character. Even in coarse-grained materials, it is expected that pollutant travel would be significantly inhibited by filtration. This indicates that in normal soils suitable for waste disposal, micro-organisms would be a minor problem and should not present any hazards to wells and other groundwater use beyond the recommended distances from waste disposal areas. Micro-organisms, therefore, are a problem only in the near vicinity of disposal systems, and do not represent a widespread pollution problem in the Statewide 208 Area.

A notible exception to the distance of movement of biological organisms is in fractured or cavernous rock systems. As shown by Allen and Morrison (1973), and by many other investigations, there can be significant distances of travel by micro-organisms in fractured rock materials. Although rock fractures are typically very small, they are, in comparison with bacteria and viruses, very large and commonly virus and bacteria can move through fractured, and particularly, cavernous rocks with very little hindrance.

The direction and rate of movement of contaminated waters are largely controlled by the nature of the geologic strata and the orientation of major bedrock fracture systems. Other conclusions of Allen and Morrison (1973) indicate: sufficient microbial filtration of drainfield effluent does not occur along crystalline rock fractures; normally acceptable percolation rates and system design and placement criteria may not adequately protect groundwater quality in mountainous areas having cystalline bedrock.

Another material present in sewage effluent is organic matter. Organic matter can be present as particulates and present as dissolved organics. Most of particulate organic matter will be filtered out with a very short distance of the soil-water interface. The organic matter normally undergoes biological and biochemical decomposition at this interface. Organic matter is substantially larger than micro-organisms present in the sewage and the soil is very efficient at filtering out organic matter. Organic matter does, however, clog soil surfaces and inhibits infiltration and seepage.

In addition to micro-organisms and organic matter, sanitary wastes have increases in dissolved mineral content as shown in Table 13. These chemical constituents generally do not render the waters unfit for most uses, however, one constituent in particular is of importance - that is, nitrogen. Nitrogen is an essential component of all living matter; it is ingested as food by man and is excreted in liquid and solid wastes. Proteins in urea undergo decomposition in most sewage and eventually end up as ammonia, nitrite, and nitrate. In the soils system, most nitrogen is converted to the nitrate form, which is highly mobile in groundwater systems and is of health significance. This change of nitrogenous material, particularly ammonia to nitrates, is done by soil bacteria in a nitrification process that is of major importance. The nitrate ion is formed by the complete oxidation of ammonia ions by soil or water micro-organisms and nitrite is an intermediate product of this nitrification process. As described by the EPA (1976)

> The reaction of nitrite with hemoglobin can be hazardous in infants under three months of age. Serious, and occasional fatal poisonings in infants have occurred following ingestion of untreated well waters shown to contain nitrate concentrations greater than 10 mg/l nitrate nitrogen. The abundance of nitrogen in sanitary wastes; its mobility in groundwater systems, and its potential harmful health affects, make this a constituent of major concern in sanitary wastes.

Other constituents of concern include metals, pesticides, and other toxic compounds. Metals have been examined in sanitary wastes, however, little is known of other toxic trace or organic compounds and their potential effect on groundwater.

Municipal Disposal Systems

Within the Statewide 208 Area, there are 20 sewage treatment plants, and 102 municipal treatment lagoons. There is little information relative to groundwater impacts of sewage treatment plants, and it is thought that the only impact might be from dewatering of sludge from sewage treatment plants. Sludge is normally dried by spreading on a sand bed. No pollution problems of this type are known in the Statewide 208 Area, but this has been identified as a possible source of groundwater problems in other areas.

Municipal sewage lagoons are widely used by small communities and isolated industrial plants (Table 14). The advantages of these pond systems lie in their simplicity in design, construction, and operation. They provide a high degree of wastewater treatment. These ponds are basically large shallow holes in the ground with an adequate capacity to hold wastewater for several months. The action of air and sunlight on the pond causes biological treatment that can be aerobic or anerobic. Water from lagoons is normally discharged to nearby stream systems or may be diverted to a land application system, or may be entirely contained within the lagoon with water controlled by seepage. In the design of lagoons, it is desirable to maintain a minimum and a maximum liquid depth to ensure proper pond functioning. Infiltration lagoons are designed to dispose of effluent by infiltration into the ground system. There has been little information obtained on the impact of lagoons on groundwater, however, lagoon effluent, again, must react with a porous media which provides excellent mechanical filtration and removes micro-organisms

TABLE 14 MUNICIPAL LAGOONS [illegible]

[illegible]	[illegible]	[illegible] Population	[illegible] (m.g.d.)	Size (acres)	Remarks
Ekalaka	[illegible]	[illegible]	.04		[illegible]
[illegible]	[illegible]	[illegible]		6.0	terrace [illegible]
[illegible]	[illegible]	[illegible]	.06		[illegible]
Belt	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Big Sandy	[illegible]	[illegible]	[illegible]	9.0	[illegible]
[illegible]		[illegible]			
[illegible]		[illegible]	.06		[illegible]
[illegible]		[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	4.3	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.075	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.5	[illegible]	terrace [illegible]
[illegible]	[illegible]	[illegible]	.07	[illegible]	terrace [illegible]
[illegible]	[illegible]	[illegible]	[illegible]		terrace [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	404	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	4.8	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	40.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	140	[illegible]	4.7	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		adjacent [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	22N 03W 33D	[illegible]	.07	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fallon	13N [illegible]	150			terrace of Yellowstone R
Flaxville	[illegible]	[illegible]			[illegible]
Fort Belknap		[illegible]			
Fort Benton	[illegible]	[illegible]	.21	[illegible]	adjacent to Missouri River
Fort Harrison	[illegible]	[illegible]			adjacent to [illegible] Cr.
Fort Peck	[illegible]	[illegible]			
Fort Smith		[illegible]			
Frazer		350	.04		terrace above [illegible]
Froid	[illegible]	330	.09	3.1	adjacent to [illegible]
Gardiner		672	.45		terrace above Yellowstone R
Geraldine	21N 11E 21CBD	370	.05	5.0	adjacent to Flat Cr
Glasgow	25N 37E 13DD	4700	1.0		terrace above Milk R
Glasgow AFB		1500			
Glasgow RID		100			
Glendive	16N 55E [illegible]AB	6305		[illegible]	terrace above Yellowstone R
Grass Range		181			
Harlowton		1375	.19	21.5	terrace above Musselshell R
Havre AFS	[illegible]N 1[illegible]E [illegible]ACAA	250			terrace above Milk R
Hays		100			adjacent to Little [illegible] Cr
Helena - State Girls School		120			Helena Valley
Helena County Hospital		[illegible]			Helena Valley
Helena - Treasure State [illegible]		[illegible]			Helena Valley

TABLE 4 (Cont.) MUNICIPAL LAGOONS IN THE [illegible]

Community	Location	1973 Population Served	Design Capacity (MGD)	Size (Acres)	Remarks
Hingham	33N 11E 23DD	262		2.0	adjacent to Hingham Coulee
Hogeland	34N 15E 29AC	192	.02	1.0	adjacent to int. Coulee
Inverness		170			prairie [illegible]
Joplin	--	200			
Jordan		529	.10		adjacent to Big Dry Cr.
Kevin		250	.025		pothole country
Kicking Horse JCC		250			
Lambert		100			
Lavina		169	.027		
Malta	30N 29E 27DA	2195	1.0	128	terrace at Milk R.
Medicine Lake	32N 56E 25C	393			terrace above Missouri R.
Nashua	27N 41E 21AC	513	.12	3.0	adjacent to Milk R.
Opheim		322	.12		
Opheim AFS		250			
Philipsburg	07N 14W 23CB	1128	.20	12.9	terrace above Flint Cr.
Plentywood	35N 55E 30	2381	.4	42.2	adjacent to [illegible] Cr.
Poplar	27N 50E 20	1389	.27	20.2	terrace above [illegible] R.
Reserve (aerated)		243	0.006		
Richey		389	0.11		
Rock Boy		300			
Roundup		2116	0.35		adjacent to [illegible] R.
Ryegate		353	0.05		[illegible]
Ryegate	10N 21E 20A	261	0.05		adjacent to Musselshell R.
Saco	31N 34E 17A	492	0.03	4.1	terrace above Beaver Cr.
Savage		300	0.04		terrace above Yellowstone R.
Scobey	33N 48E 1AD	1426	0.42	3.[illegible]	adjacent to Poplar R.
Shelby	32N [illegible]	3111	0.42	42.3	adjacent to intermittent stream
Sheridan	04S 05W 27BDC	636	0.067	6.4	adjacent to Indian Cr.
Sidney	22N 59E 02B	4543	1.4	71.0	adjacent to Yellowstone R.
Stanford	[illegible]	505	0.04	6.0	terrace above [illegible] Cr.
[illegible]	[illegible]	[illegible]	0.1	10.[illegible]	terrace above [illegible] R.
Superior	17N 25W 36BDC	993	0.09		adjacent to Clark Fork R.
Terry	[illegible] 16B	870	[illegible]	13.2	terrace above Yellowstone R.
Thompson Falls	21N 29W [illegible]	500		5.0	adjacent to Clark Fork R.
Three Forks	02N 01E 04DDD	1188	2.0	18.3	adjacent to Jefferson R.
Townsend	07N 02E 3[illegible]	371	0.01	[illegible].5	adjacent to Missouri R.
Turner		100			terrace above Hickley Creek
Twin Bridges	03S 06W 22DD	[illegible]3	0.0[illegible]	6.0	adjacent to Beaverhead R.
Valier	29N 05W [illegible]	651	0.04	10.7	terrace at Lake Frances
Virginia City		149	0.012		terrace above Alder Cr.
[illegible]	[illegible]	200	0.0[illegible]		
Warm Springs		2020	0.4		adjacent to Warm Springs Cr.
Westby		287			
West Glendive	16N 55E [illegible]	1222	0.17	[illegible]	terrace above Yellowstone R.
West Yellowstone		262	[illegible]		
Wibaux	21N [illegible] 23DD	1222	2.0[illegible]	11.0	adjacent to [illegible] Cr.
White Sulphur Springs	09N 06E 23[illegible]	202		12.0	adjacent to [illegible] Cr.
Winnett	15N 27E [illegible]	244	0.2		adjacent to Beaver Cr.
Winifred		190	0.21		adjacent to Dog Cr.
[illegible]	[illegible]	221	0.03		adjacent to [illegible] Cr.
Wisdom		54			[illegible] R.
Wolf Point	27N 45E [illegible]	3215	1.0	41.0	adjacent to Missouri R.

and organic matter. The main concern in lagoons is the movement of nitrate into groundwater. There is very little information available on the impact of lagoons on groundwater systems and the effect of nitrogen, and possible nitrification-denitrification, has not been investigated in any detail. Information that is available is conflicting as to the fate of nitrogen in lagoon systems and in percolating waters. Most lagoons in Montana are located near streams and it is thought that a sector of polluted groundwater is present between the lagoons and the nearby surface water (assuming groundwater flow direction to be toward the stream as recharge). As this groundwater moves, there will be some change in chemical quality, and pollution of the groundwater system. There have been very few problems of groundwater pollution reported from lagoons; however, generally there is little habitation or use of groundwater in the vicinity of lagoons.

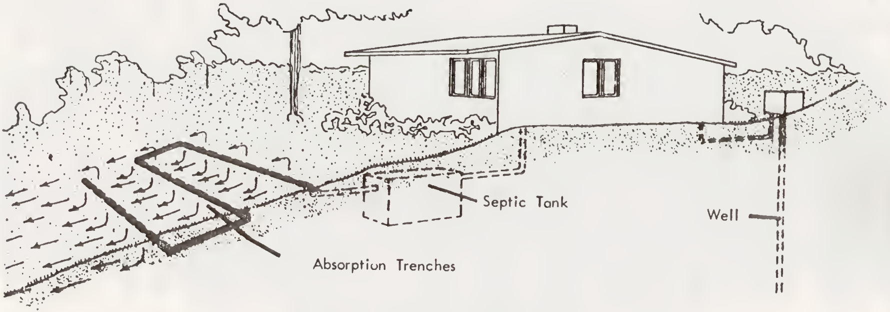
Land Disposal

Land disposal is becoming increasingly popular in Montana due to the limitation on disposal of sanitary wastes effluents into surface water systems. There presently are land disposal systems operating in Missoula, Gregson Hotsprings, Great Falls, and Helena. The Subdivision Bureau requires that systems be sized to hold water during the nongrowing period of the year which generally ranges from 150 to 200 days in Montana. Monitoring wells are required for groundwater shallower than 15 feet (T. Wing, pers. comm., Feb., 1978). Land application of sanitary wastes allows the use of the "living filter" (soil) to effectively treat effluent. Soil factors including grain size, organic matter, and mineralogy affect the reaction between the effluent and the soil materials. Removal of virus and bacteria and organic matter during lagoon seepage is excellent.

Phosphorus, particularly in the orthophosphate form, typically reacts with all soils and is generally almost compeltely removed from solution within a short travel distance. In areas where crops are grown, which is common in Montana land disposal systems, some uptake of phosphorous and nitrogen is expected. The removal of nitrogen varies considerably depending on soil type, design and mode of application of wastewater, climate and vegetation cover.

Individual Disposal Systems

Individual disposal usually consists of the use of septic tanks and drain fields or cesspools or septic tanks combined with seepage pits. Although cesspools and seepage pits were widely used in the past, today individual sewage disposal is dominated by the use of septic tanks with drain fields. Figure 19 shows a typical septic tank and drain system. Its components are a septic tank which removes settable solid matter and the subsoil disposal system which receives the effluent from the septic tank and allows seepage into the ground. Important factors to be considered in design of a drain system are site suitability including soil, percolation rate, depth and flucuations of the water table, and proximity towater bodies. The impacts of septic tanks on groundwater are similar to those of lagoons or land disposal. The material is filtered by the soil with excellent removal of micro-organisms and organic matter; however, the nitrogen compounds, particularly nitrate, are not absorbed in the soil system to any appreciable extent. This nitrogen, however, can be absorbed by plants and utilized in their growth during the growing season. The normal range of increase of dissolved materials in domestic sewage is shown in Table . As noted in this table, the increase in nitrogen is from 20 to 40 mg/l as N. In normal soils there is a substantial removal of phosphate and a movement of nitrogen



The well should be at a higher level
than the septic tank system to protect
it from sewage contamination.

Figure 19: Schematic of typical septic tank system
Source:

Federal Housing Administration
No. 556 (no date)

becomes a most important aspect of individual domestic sewage disposal systems. In Montana there are a number of areas of concern due to presence of subdivisions and increased loads of septic tank wastes to groundwater systems.

Subdivisions

Subdivision of land is greatly increasing in Montana. Although a significant portion of Montana's 150,000 square miles are relatively free of development pressures (public land and other), lands adjacent to urban areas, lakes and streams, and productive farm areas, are subject to increasing subdivision activity. (A subdivision is currently defined by Montana law as the division of land into one or more parcels containing less than 20 acres). This growth in subdivision activity is illustrated in the number of subdivisions approved by the DHES (Subdivision Bureau) in recent years:

YEAR	SUBDIVISIONS APPROVED	ACRES SUBDIVIDED
FY 1975-76	915	6,204
FY 1976-77	1578	9,430
FY 1977-78*	2768	14,970
FY 1978-79*	3447	18,410

*Indicates DHES - Subdivision Bureau projections

These figures include only those subdivisions approved by the DHES; many other subdivisions are either denied by the DHES, or are exempt from the review process.

Recent land division within the Statewide 208 Area has been most active in the following counties: Ravalli, Missoula, Powell, Park, Musselshell, Cascade, Lewis and Clark, Jefferson, and Mineral. These trends were determined through inventories of certificates of survey and subdivision plats filed (July 1, 1973 to Fall, 1976) under the Subdivision Platting Act and other county records of land subdivisions (prior to the Act). Inventories

were completed by the Department of Community Affairs (DCA) in 1977 and the Environmental Information Center (EIC) in 1975.

A 1972 study (DCA) noted that two-thirds of new subdivisions were not in compliance with existing law (subdivision of unsuitable land; water supply, sewage, and solid waste disposal problems, poorly designed lots and roads, etc.). Additional public conern with the problem of unregulated subdivision activity led to development and passage of more comprehensive regulatory controls (outlined in Section IX of this report). Local governments are now responsible for regulation of subdivision design and location; approximately 90 percent of the counties have adopted the state's model subdivision regulations (developed by DCA).

The standard review procedure for subdivisions includes: evaluation by local planning staff with recommendations for denial or approval; planning board action upon the staff's evaluation, and related public opinion, resulting in recommendation for denial or approval to the local governing officials. Subdivisions must also be reviewed by the DHES (Subdivision Bureau) to assure that water supply and sewage treatment systems will adequately protect water quality for public, domestic, and other beneficial uses.

Despite these review procedures, numerous land divisions occur without review. Some of these subdivisions are legitimate exemptions from the law (see Section IX, Subdivision and Platting Act); however, many more subdivisions evade the review process through abuse of the exemption clauses. DCA estimates that approximately 70 percent of subdivided acreage (20 acres or less) occurs without proper review, considering all subdivided acreage, approximately 93 percent occurs outside the review process.

With increasing subdivision activity, and the limitations of the review process, protection of public water supplies and regulation of domestic waste disposal are major areas of concern. Several methods of water supply and waste disposal are utilized in residential subdivisions in Montana. Of particular importance are domestic waste disposal systems and their potential for impacts to groundwater quality. Septic tanks (including cesspools and seepage pits), sewage lagoons, treatment plants, and land spreading are described later in this section. Table 15 and Figure 20 show a general delineation of central and individual systems used in residential subdivisions. Although not indicated, percentages of the various systems used in minor subdivisions are believed to be similar to those for major subdivisions. Additionally, it is estimated that nearly all residential construction associated with occasional sales utilize individual water and sewer systems (J. Melstad, DHES - Subdivision Bureau, pers. comm.). Using these figures, it is estimated that approximately 50 percent of the subdivided lots utilize individual waste treatment systems. No statistics are available regarding additional use of individual systems in subdivisions exempt from review or on existing subdivided lands.

This incidence of use of individual waste treatment systems creates a situation of increasing potential for groundwater pollution. In an attempt to limit the potential for groundwater contamination from these systems, several counties have adopted procedures for review of septic tank installation. Within the 41-county Statewide 208 Study Area, only seven counties have adopted any regulatory measures (Cascade, Deer Lodge, Lewis and Clark, Lincoln, Missoula, Park and Ravalli). Several other counties are working on regulatory controls for septic system usage (Blaine, Broadwater, Hill, et. al.). The review procedures have been more effective in controlling improper use of septic systems in Missoula and Lewis and Clark Counties;

PRESENT AND PROJECTED NUMBER OF SUBDIVISION LOTS

SUBDIVISION BUREAU

Figure 20.

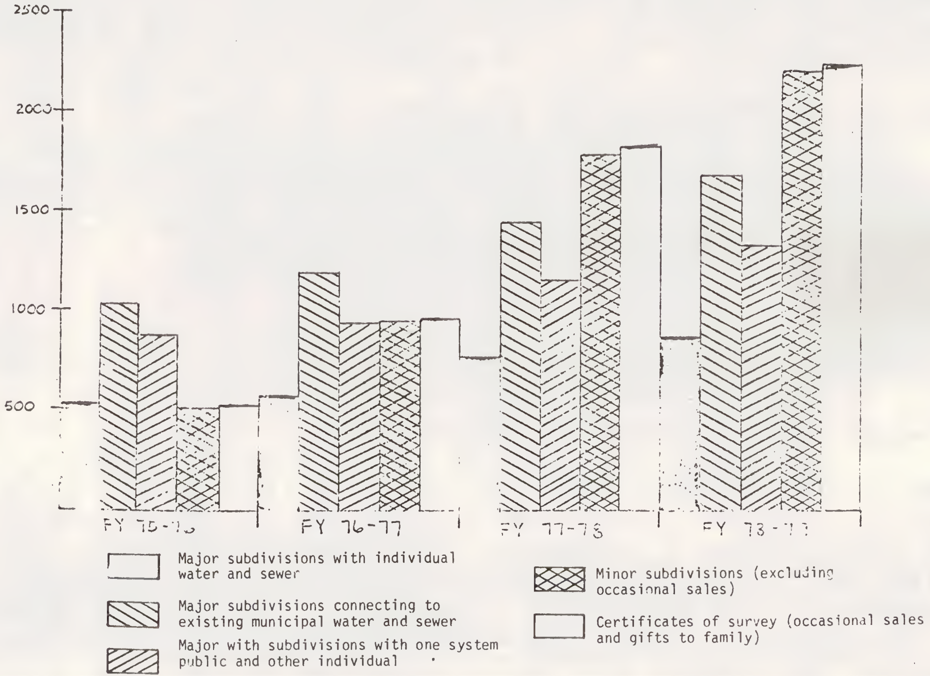


Table 15: Sanitary waste disposal in residential subdivisions

TYPE	NUMBER OF SUBDIVISIONS				ACRES				LOTS			
			(Projected)				(Projected)				(Projected)	
	FY 75-76	FY 76-77	FY 77-78	FY 78-79	FY 75-76	FY 76-77	FY 77-78	FY 78-79	FY 75-76	FY 76-77	FY 77-78	FY 78-79
[illegible]JOR SUBD. WITH INDI-DUAL WATER AND SEWER	29	34	40	47	1479	1740	2040	2390	543	640	750	880
[illegible]OR SUBD. CONNECTING EXISTING MUNICIPAL [illegible]TER AND SEWER	39	46	54	63	417	490	580	680	1043	1220	1440	1690
[illegible]OR WITH [illegible] SYSTEM [illegible] AND OTHER INDI-DUAL	47	55	65	76	915	1070	1260	1480	820	960	1130	1330
[illegible] SUBD. (EXCLUDING [illegible])	251	454	821	1026	1313	2370	4290	5360	538	970	1760	2200
[illegible] OF SURVEY [illegible] AND [illegible]IFTS TO FAMILY)	547	939	1788	2235	2080	3760	6800	8500	547	990	1790	2240
TOTALS	915	1578	2768	3447	6204	9430	14970	18410	3491	4780	6870	8340

other counties have less comprehensive review procedures or are less effectively applying and enforcing their adopted regulations (T. Hing, DHES Subdivision Bureau, pers. comm.).

Related Problem Areas

Groundwater pollution from disposal of sanitary wastes has not been accurately documented in the Statewide 208 Area. Although sufficient data is not available, it appears that lagoon and land spreading treatment methods pose less of a problem then septic tanks systems. Most suspected problems arise from improper physical siting and/or inadequate design and installation of these systems.

The DHES Subdivision Bureau has recently completed a preliminary evaluation of potential water pollution problems related to subdivision (December, 1977). The Statewide 208 Area study identified and prioritized areas of suspected or potential impacts to groundwater quality. Evaluation was done through development and utilization of a point system for prioritizing suspected problems. Criteria used in this evaluation system included:

- Depth to groundwater
- Percolation rates
- Slope
- Total number of lots
- Present density
- Wells
- Sewage disposal system
- Susceptibility to flooding
- Age of the subdivision
- Proximity to surface water
- Ratio of groundwater flow to effluent flow
- Development potential

The report recommended that two year (minimum) field investigations be conducted at the five most highly prioritized subdivisions:

1. South Libby Flats — South of Libby
2. Sewell's Addition # 4 — Helena Valley
3. Opportunity — East of Anaconda
4. H & R Addition — Southeast of Hamilton
5. Five Acre Tracts — West of Livingston

Investigations should include chemical and microbial monitoring to assess effects the subdivisions have on water quality.

A further understanding and illustration of the impacts on septic tank systems on groundwater is given in the case histories listed. These case histories result from investigations conducted in portions of the Statewide 208 Area, where septic tanks were thought to be causing groundwater degradation.

Helena Valley

Approximately 2,000 people lived in the Helena valley as of 1972, and a population of about 4,000 was projected for the valley for 1990 (Northwest Planners Association, 1971). This valley, located just north of the city of Helena, is a large, alluvial valley, consisting of basin fill deposits ranging in age from Tertiary through Quaternary. This fill consists of clay and silt, interbedded with sands and gravels and is highly variable in composition from area to area. Hydrologically the valley contains abundant groundwater with the general direction of flow to the east towards Lake Helena. Groundwater is shallow in much of the valley, and most wells are 25 to 60 feet deep. Typically the valley has several permeable water zones separated by relatively impervious silt and clay layers. Drillers normally complete wells in the "second water" for domestic use. The widespread use of septic tanks and individual water wells in a shallow groundwater system caused concern about possible contamination. The U.S. Geological Survey conducted a sampling program in the valley to assess the quality

/

of water and to determine if there was any groundwater pollution (Wilke and Coffin, 1973). A total of 95 samples were tested in the valley, including tests for coliform bacteria, trace elements, presence of detergents, and nitrogen. Results of this investigation show that, with few exceptions, groundwater quality in the Helena valley was of good quality. The conclusion of Wilke and Coffin (1973) was

> Contamination of groundwater by coliform bacteria and by constituents indicative of man's activities is presently (1972) not a general problem.

Additional tests were taken in 1974 with essentially the same results. To date, groundwater quality in the Helena valley does not seem to be significantly impacted by individual waste disposals.

Southwest of Great Falls

It was reported that a mobile home court utilizing a central septic tank system experienced a rise in groundwater which caused pollution on an adjacent property. Geologically the area consisted of aeolian (wind blown) sand, ranging in depth from a few inches to over ten feet overlying a clay or sandy clay which is at least 40 feet thick. A number of test holes were drilled to determine the area affected by the high water table. The problem area is near the west end of Sunnyvale Road southwest of Great Falls. The area had approximately 40 trailers. Although there were some samples that were reported to have high coliform bacteria concentrations, no detailed examination of groundwater pollution was made. Investigation did show that a substantial volume of groundwater was put into the ground by the septic system and some groundwater pollution may have occurred. However, no data was developed on the extent or the character of the groundwater pollution.

Melrose

The community of Melrose is an old community on the banks of the Big Hole River, south of Butte, Montana. Most lots in town are small (25 x 100 feet), and most wells are shallow and constructed in a coarse gravel underlying the town. Water in this unconsolidated alluvium is in hydrologic contact with septic tanks and cesspools. Most wells and waste disposal systems are not properly constructed and the community has had public health problems in the past that may have been related to these sanitary conditions. The use of both private wells and waste disposal systems in the shallow, unconsolidated alluvium has caused concern. All wells in the community penetrate these unconsolidated materials to depths of 25 to 40 feet. The groundwater system is in hydraulic contact with the Big Hole River on the west edge of the town and with Camp Creek on the south edge. Direction of groundwater movement is to the southwest. Investigation indicated that fewer than 5 percent of the wells were properly sealed and many were within 50 feet of septic drain fields or cesspools. A major problem is seasonally high groundwater tables that submerge cesspools and septic tank drain fields and inhibit their proper functioning. Records show groundwater to be shallow, ranging from 0.3 feet to 10.2 feet below the ground surface with an annual groundwater flucuation of about four feet. As part of an assessment of the community for a possible central water or sewer system, Botz (1977) conducted a brief investigation of groundwater quality. To determine sanitary conditions of wells in the community, a total of 24 bacterial, and 30 chemical samples were obtained from wells. During the sampling period, the water table was three to eight feet below the ground surface. Results of bacteriological tests showed negative results in all wells for the presence of fecal coliform bacteria, and tests of nitrate plus nitrite showed the highest to be 9.1 mg/l and the lowest, 1.4 mg/l. Three

wells have nitrate plus nitrite greater than 2.5 mg/l, suggesting the possibility of nitrogen enrichment from sanitary wastes.

Although the investigation showed that most of the individual sewage disposal systems were inadequate, and were too close to wells, groundwater pollution, as measured by fecal coliform organisms, was not present in May, 1977. Nitrogen levels indicated probably impacts of sewage on the groundwater system. It is possible that during periods of high water when septic tanks and cesspools are submerged, this community may have sanitary problems that were not apparent at the time of the investigation.

Lincoln

The community of Lincoln, Montana is on an unconsolidated alluvial floodplain adjacent to the Blackfoot River in western Montana. The community has a high groundwater table and uses individual wells and septic tanks for water and waste disposal. The community has a population of about 2000 persons and is rapidly growing. There has been concern that the shallow alluvial aquifer may becom e contaminated from septic tank waste disposal. The U.S. Geological Survey sampled a number of wells in Lincoln to determine if there were any polluted waters. Groundwater in the area is a calcium-bicarbonate type water of excellent quality, with small amounts of nutrients, and low concentrations of metals. It appears to be suitable for all uses and is a typical western Montana high-quality groundwater.

A total of 41 water quality samples were taken in Lincoln from October 7 to 9, 1974, and tested for nitrate plus nitrite nitrogen. Samples were also subsequently taken to test for ammonia, phosphate and to retest for nitrate plus nitrite-nitrogen. Results of these tests showed nitrate plus nitrite ranged from 0.03 to 0.75 mg/l as nitrogen. This is a low concentration of nitrogen and is typical of many groundwaters in western Montana. These

data showed no evidence of groundwater pollution. Tests of ammonia showed all wells had less than .01 mg/l and phosphorus contents also were low. Results of testing in Lincoln has not shown any evidence of chemical pollution from septic tanks and no further work has been done in this community.

Libby

There has been concern in the Libby Flats area near Libby in northwestern Montana due to high groundwater tables and widespread use of septic tanks and individual water supply wells. Libby Flats is on an outwash terrace with shallow to moderately deep gravelly, loamy, fine, sandy soils. The ground surface is gently sloping to undulating. Much of the urbanization around Libby and Troy is on these soils. Well depths generally range from 10 to 90 feet and wells yeild from 15 to 20 gallons per minute.

The Libby Flats is a flood area and is a designated floodplain with a high groundwater table. There are actually five subdivisions in the Libby Flats area. The aquifers are unconsolidated, have good transmissibility, and percolation rates are generally high. It was reported that about 30 percent of the wells are contaminated, but there is no recorded raw sewage problems. The aquifer is alluvium and glacial outwash along the Kootenai River and groundwater is abundant. A number of wells were sampled by the U.S. Geological Survey in the Libby Flats area and results of this sampling showed some wells to have high nitrogen concentrations ranging from 0.0 to 29 mg/l as NO_3 (U.S. Geological Survey, Unpub. chemical data).

Surface Impoundments

As described by Ricks:

> In 1968, over 240 reservoirs in Montana each stored 50 acre-feet or more water for many uses. Most of these reservoirs were developed for hydroelectric power, flood control, or fish and wildlife, but many serve such withdrawal uses as irrigation and stock water as well. In addition, over 1,000 other impoundments have been constructed for the sole purpose of irrigation or stock water, and some of these are also used for recreation. The distinction between reservoirs for withdrawal use and for instream use is not important, nor in fact very clearly defined, because most water supply reservoirs also serve such uses as conservation and recreation.
>
> The total area of these water surfaces is about 900,000 acres, or 1,400 square miles, and the total storage is 37.5 million acre-feet. Since annual evaporation from shallow water surfaces in Montana averages between 35 and 47 inches, total evaporation from all reservoirs constitutes a very large quantity of water. This quantity has been estimated at over 1 million acre-feet per year (993 mgd) from reservoir surfaces alone. Although much water would be conserved if evaporation from reservoirs could be entirely suppressed, not all evaporation water loss can be charged directly to the reservoirs. Some was occurring before the reservoirs were built, in the form of evaporation and transpiration from the land areas and stream surfaces later flooded.

In addition to storage reservoirs there are a large number of other types of impoundments in the Statewide 208 Area including sewage treatment lagoons, tailings ponds, industrial cooling ponds, pits, and basins. All of these impoundments except storage reservoirs are discussed in other sections of this report.

All reservoirs increase the salt concentration of water through evaporation. This surface water quality problem is compounded because of more seepage from reservoirs than there would be from a natural stream system. Extensive aerial examination of Montana by the authors has shown that commonly, downstream from reservoirs, there are saline deposits in the stream channel and on the streambanks, particularly in the north and northeast part of the Statewide 208 Area. Most surface impoundments are not lined, however, in most ponds some effort is made to seal the bottom either by

compaction or by use of impervious soils or, in some cases, by lining with an impervious membrane liner. Although the permeability of pond bottoms is usually low, a large soil surface covered by water will, in time, seep substantial quantities of water into the ground. These percolating waters usually surface downstream of the reservoir creating salt encrusted areas at the soil surface where evapotranspiration is occurring. This effect combined with the increase of salinity in ponds due to evaporation, can significantly degrade groundwater associated with impoundments.

There is practically no data available on the overall impact of reservoir storage on groundwater quality, and no specific investigations of this relationship are known in the Statewide 208 Area. It is clear that reservoirs do enhance the movement of water into the groundwater and can cause charges in groundwater quality. Sometimes, however, groundwater quality may be improved by leaking reservoirs. This would be dependent upcn the soils, site, climate, and water quality of both surface water and groundwater beneath the impoundment.

TABLE 16

SUMMARY OF GROUNDWATER PROBLEMS IN THE STATEWIDE 208 AREA

Petroleum Related

Problem	Location	Date	Impact	Comment
Brine leakage from injection wells	Near Cut Bank	1976	Saline soils and groundwater	Possibly caused by brine injection in the Cut Bank oil fields
Brine seepage from unlined pits	Northeastern Montana, Goose Lake field	1975	Trees killed by brine seepage, abandoned wells were flowing water, and soil damage by salt water	Seepage from brine pits. Most problems corrected after initial field report completed
Brine seepage from disposal pit	36N58E33 Goose Lake field	1975	Damage to domestic water well; high concentrations of sodium chloride	Well may have been damaged by leakage from the disposal pit. Oil company directed to either discontinue use of the disposal pit and backfill it, or to line the pit
Alleged well pollution near oil fields	Cut Bank - Sweetgrass area		Unknown	Investigated by the WQB. Samples from these wells did not confirm pollution from petroleum activities; complaints have continued
Brine seepage from unlined emergency pits	Dwyer oil field 32N58E	1975	Unknown; concern that rapid brine seepage may affect the Medicine Lake refuge	No specific problems were described and present status of the reported unlined pond is unknown

Problem	Location	Date	Impact	Comment
Oil spill	Raymond field 36N54E		None	Field investigation showed no problems with oil and brine discharge pits. No detailed information
Brine seepage from unlined pit	Outlook field 36N52E	1975	Land south of pit was barren for at least 100 feet by 50 feet. Deep, eroded trenches extending from pit	Pit was taken out of service after the site visit
Crude oil seepage and brine spills	Murphy field, North of Poplar	1975	Brine had spilled from ponds. No water injection well was found flowing water with a conductivity of 90,000 umhos. Shallow groundwater appeared to be degraded by brine leakage	Problems seemed to be localized. Main damage appeared to be to small tracts of land and some impacts on groundwater at the Murphy oil field
Gasoline pollution	Deer Lodge	April, 1972	Strong gasoline odors in municipal water supply. Water surface in the well was covered with gasoline	Well was rehabilitated and has been operating successfully
Diesel fuel spill (several thousand gallons)	Deer Lodge	1970-71	Migrating toward the Clark Fork River and threatening a municipal supply well	No detailed investigation of problem
Gasoline spill (22,000 gallons)	Missoula	Sept., 1973	Petroleum odors in water wells. Strong odors at times, nonexistent during most of the year	Petroleum company provided carbon filtration units for some wells to remove organics. Gasoline has moved about 4000 feet in two years
Gasoline spill (126,000 gallons)	Missoula	Sept., 1972	Well contamination 3000 feet from spill	Pipeline leakage for 30-60 days. New wells drilled, carbon filters installed, odors became less noticeable

Problem	Location	Date	Impact	Comment
Gasoline leakage (10,000 gallons)	Conrad retail gasoline station	March, 1975	Gasoline and oil in basement. Heavy fumes	Examined by WQB in June, 1975. Corrective program outlined
Diesel fuel spill (18,000 gallons)	Glendive, 2000 feet from Yellowstone River, 3000 feet from Glendive Creek	1975	No known groundwater contamination	City engineer indicated he would examine the area. No known detailed investigation
Diesel fuel pollution	Livingston groundwater drain	1977	Impact to surface waters at the drain outlet	Source unknown. May be related to fuel oil storage at a nearby railroad. Under active consideration by the WQB
		Agriculture Related		
Saline seep (200,000 acres)	Northcentral, central, and northeastern Montana; see Figure	Continuous	Impairs or eliminates productive plant growth. Contaminates wells with saline waters. Pollutes streams	Problem is understood fairly well. Needed changes in farming practices have been slow.
Pesticide disposal	Great Falls		Contaminated soils. Health hazard to pets and children	Pesticides flushed into an open seepage ditch
		Wood Products		
Infiltration of log spraying water	Bonner, wood products plant	1975	Odor and taste problems in domestic wells located near ponded effluent	Corrective steps taken to improve the operation. Company worked with community on improvement of water supply

Problem	Location	Date	Impact	Comment
Paper mill wastewater seepage	Frenchtown	1974	Complaints of phenol odors in domestic wells	No substantial cases of groundwater degradation peripheral to the Hoerner-Waldorf property
		Mining and Mineral Processing		
Acid mine drainage	Numerous (see Schmidt and Botz, 1968)	Continuous	Seepage to streams, severely impacts aquatic life	It is seldom cost-effective to abate/correct these problems. Attempts are being made to abate acid drainage at Hughsville and Cooke City
Opportunity tailings ponds seepage (4000 acres)	Opportunity	Continuous	Possible saturated solutions of calcium sulfate and small quantities of metals beneath and peripheral to ponds	No detailed investigations have been done. Movement of water is eastward or northeasterly to the Clark Fork River
Warm Springs tailings ponds seepage (1600 acres)	Warm Springs	Continuous	Seepage of metals downstream from middle pond to a lower pond. Overall impact unknown	No detailed investigation of groundwater conditions in the area. Major groundwater pollution problem and thought to be present
		Solid Waste		
Solid waste disposal site	Livingston, adjacent to Yellowstone River	1977	Groundwater was degraded substantially by both organic and inorganic constituents. Seeps to Yellowstone River	Leachates downgradient from disposal site were typical of other landfills in the U.S.

Problem	Location	Date	Impact	Comment
Solid waste disposal site	Alder	1977	Groundwater pollution during spring runoff and high seasonal groundwater	No control of septic tank pumpings or hazardous wastes
Solid waste disposal sites	Anaconda, Butte, Cascade, Choteau, Darby	1977	Creation of leachates due to precipitation, high seasonal groundwater, or spring runoff	These communities have intermittent seepage of leachates. Have a low to moderate potential for pollution
		Sanitary Waste		
Domestic sewage, septic tank failure	South Libby flats (2,200 residents)	Continuing	Potential contamination of domestic wells	DHES recommended further monitoring
Well flooding	Sewell's Addition #4, Helena Valley (41 acres)	1971-Continuing	Potential contamination of domestic wells	Further subdividing of this project has been delayed
Sewage treatment systems failure	Opportunity (600 families)	Continuing	Threat to human health-fecal coliform contamination of wells	No definite plans implemented for installation of water or sewer systems
Cesspool failures	H & R Addition, Hamilton (100 lots)	Mid-1960's - Continuing	Sewage entering high groundwater proximity to Skalkaho Creek	Further study recommended by DHES
Flood irrigation affecting sewage systems	Five Acre Tracts, Livingston (407 units)	1930's - Continuing	Contaminated domestic wells	Contaminated irrigation return flows enter Yellowstone River

MONTANA

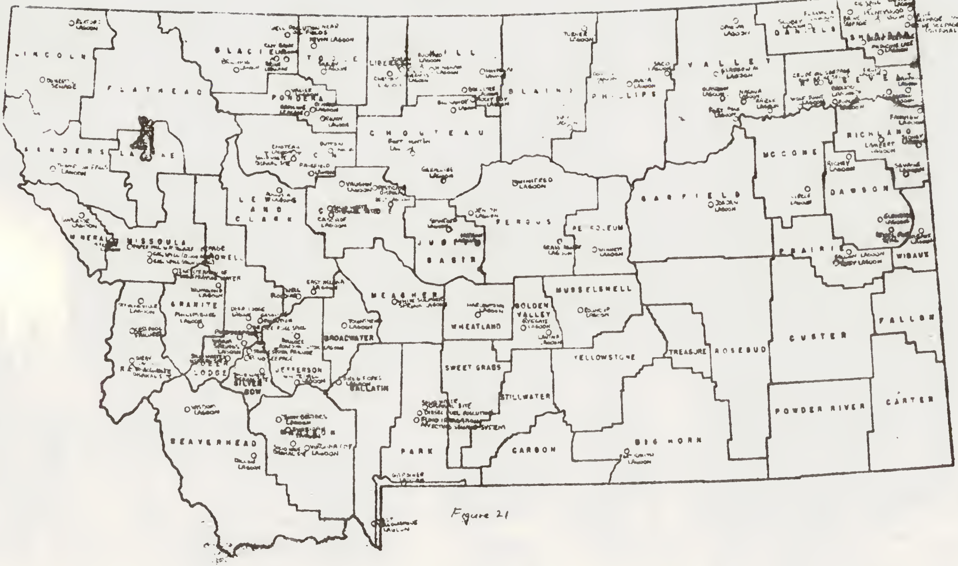


Figure 21

GROUNDWATER QUALITY MONITORING

The monitoring of groundwater quality in the Statewide 208 Area can be designed for several purposes. These are:

1. To determine trends in groundwater quality;
2. To determine cause-effect relationships between specific land practices and groundwater quality; and
3. To detect entrance of pollutants into a groundwater system.

Presently, in the Statewide 208 Area, there is no general groundwater monitoring program in effect. The only groundwater monitoring that does occcur is related to specific problems, or specific facilities.

Existing and Planned Monitoring

The Montana Bureau of Mines and Geology (MBMG) presently monitors about 1000 wells in Montana (Marvin Miller, pers. comm., Feb.,1978). About 350 of these are located in coal fields in eastern Montana. Most of these sites are outside the Statewide 208 Area. Water levels are regularly checked at all wells and selected wells are sampled for chemical quality. Parameters checked are variable depending on the location of the well, aquifer, and what particular activity is being monitored. Two hundred fifty wells are monitored in cooperation with the USGS, again, with a large proportion of these in the southeast Montana coal area. Water levels are measured in these wells on a quarterly basis and specific conductance and temperature data are obtained. About 50 wells have recorders for continuous water level information. Saline seep and its impact on groundwater quality, is monitored by a network of 400 wells located in northeastern and central Montana. These wells are checked periodically for water level, specific conductivity, and temperature. Of the 1000 wells used for monitoring groundwater quality by the MBMG, probably one-half are within the Statewide 208 Area. About one-half

of the data collected in the entire monitoring program will be published semi-annually as open-file reports. According to Miller (pers. comm., Feb., 1978), the MBMG is attempting to coordinate most of the groundwater monitoring done in Montana into one program.

The Water Quality Bureau (WQB) has no program of its own for groundwater quality monitoring on a broad scale. If complaints are filed with the Bureau, necessary sampling is done to determine whether a problem exists and, if so, who is responsible (Fred Shewman, pers. comm., Feb., 1978). One MPDES permit, allowing Hoerner-Waldorf to discharge from wastewater ponds, requires that this company monitor a network of wells for water levels, biochemical oxygen demand, nutrients and several other paramenters (Kevin Keenan, pers. comm., Mar., 1978). Another permit, issued to the EXXON Corporation in Billings, requires monitoring of groundwater quality in the vicinity of its operations. EXXON monitors the movement of organics that have entered the shallow groundwater system adjacent to the Yellowstone River. Well monitoring data is also gathered by the Anaconda Company in cooperation with the Water Quality Bureau. These data supply information about groundwater movement and quality near the Anaconda Company wastewater ponds near Opportunity, Montana. A Water Quality Bureau monitoring network for groundwater, still in the planning stage, will begin in fiscal year 1979 (Dick Karp, pers. comm., Marc., 1978).

The U.S. Geological Survey (USGS) has a water quality sampling program associated with its groundwater studies in southeastern Montana. About 1000 wells, mostly in southeastern Montana coal fields, have been sampled on a one-time basis. Any monitoring of these wells is done as part of a coordinated effort with the Montana Bureau of Mines and Geology (Joe Morreland, pers. comm., Mar., 1978). Most sampling done by the USGS in Montana is done

as part of a specific project. These projects include a water resource investigation in Lake County, and extensive work in the coal fields in southeastern Montana, both outside the Statewide 208 Area. The USGS is also involved in water quality sampling related to geothermal water resources throughout southwestern Montana (Joe Morreland,pers. comm., Mar., 1978).

Most of the groundwater sampling done by the USGS is not part of a monitoring network, that is, most of the groundwater sampling is designed to determine geologic and hydrologic conditions in specific areas. They have no groundwater monitoring network that is designed to measure groundwater quality changes with time.

The Montana Department of Natural Resources and Conservation (DNR&C) has no groundwater quality monitoring network in Montana. They do, however, monitor well water levels in several areas, Turner-Hogeland, Larslan-Opheim-Flaxville, and near Choteau (Tom Patton, pers. comm., Mar., 1978). Observations of these water levels is in direct response to increasing use of local aquifers for irrigation water supply. According to Patton, small, short-term projects are handled by DNRC. If the preliminary work done by DNRC indicates the need for extensive investigation, a coordinated effort involving the USGS or the MBMG is requested. Since well monitoring is on a problem response basis, the DNRC has no specific program for future observations. Some preliminary work has been done in the Radersburg and Ravalli County areas that may lead to future monitoring by DNRC (Tom Patton, pers. comm., Marc., 1978).

The Soil Conservation Service (SCS) has no present groundwater monitoring network in Montana. They do have a drilling rig that assists conservation districts with wells and is used for soils salinity investigations in saline

areas (Wally Jolly, pers. comm., Mar., 1978). The SCS coordinates with the MBMG on saline seep problems, supplying baseline data on extent and recovery of saline soils. According to Jolly, the SCS is required to set up water quality monitoring programs on major resource conservation and development projects such as dams and large diversion structures.

The SCS presently is evaluating monitoring needs of three areas, one near Bozeman Creek, another on Lower Birch Creek near Conrad, and an area near Bannack on Grasshopper Creek. The monitoring network near Bannack is being developed in coordination with the Montana Fish and Game Department and is related to an old mine-tailings problem. An SCS project involving rip-rapping and diversion of Grasshopper Creek away from the spoils area will be investigated in this project.

Toxic Wastes

There are a number of activities in the Statewide 208 Area that produce toxic wastes that can impact groundwater. These toxic wastes include brine associated with oil and gas development, seepage from feedlots, organic wastewaters associated with paper products, municipal lagoons, and sanitary wastes in land disposal systems.

Wastes that are concentrated and can cause significant groundwater pollution problems, need to be monitored near their source to ensure detection within a short distance to prevent movement into the aquifer and widespread pollution. The problem with this type of monitoring is the large number of facilities that must be monitored including many brine pits associated with oil and gas production, many fuel storage locations, and many municipal lagoons. Obviously a few locations, such as areas of land disposal of sanitary wastes, and paper products wastewater storage areas, can be monitored.

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Other facilities that store toxic materials such as fuel storage and petroleum production wells would require installation of a large number of monitoring wells. To monitor brine storage ponds, an estimated 1,000 monitoring wells would be needed in Montana. Monitoring of production wells or abandoned wells used in exploration or development, would require a prohibitively expensive well drilling network. Monitoring, thus, is not a feasible technique for assessing the potential impact of these activities on groundwater systems. Installation of monitoring wells at brine pits probably should be done in areas where these pits are unlined and future pits should include monitoring provisions on a site-by-site basis.

Cause and Effect Relationships

There are a number of activities occurring in Montana that are impacting groundwater; however, cause and effect relationships have not been fully demonstrated. These activities include saline seep, irrigation, feedlots, and municipal lagoons. All of these activities have been occurring in Montana for a number of years and the objective of monitoring should not be to detect and prevent contamination of an aquifer, because the aquifers already have been contaminated. The objective should be to determine cause and effect relationships between the activity and groundwater quality. The impact of sewage treatment lagoons on groundwater systems, for example, is not well known. A key factor in investigation of lagoons is the nitrogen distribution in seepage from lagoons. There is some data to suggest that a significant reduction in nitrogen occurs in lagoons, and that underground water systems are not severely impacted by lagoon effluents. Similarly, the effect of irrigation practices, both sprinkler and flood, on groundwater is poorly understood. The cause and effect relationships and the mechanism causing salinity, needs to be determined using a groundwater monitoring system.

To examine irrigation effects, representative areas need to be selected and monitoring wells located to show variations in groundwater quality, upgradient and downgradient of the irrigated area. Monitoring could also be used to show the quality changes in groundwater between an irrigation system and an adjacent land area that has not been irrigated, but has similar climate, soils, and groundwater conditions.

The general mechanism of saline seep, as it relates to shallow water table aquifers, has been examined in a number of locations in Montana. However, monitoring is needed to understand the impact of salinity on the deeper, more regional aquifers. This would involve selection of an area with a relatively shallow regional aquifer in an area that is being considered for land conversion from range to dryland farming, and where saline conditions may develop. Monitoring would show impacts of these waters on the regional aquifer system. Although it is logical to assume salinity is affecting such aquifers, the extent and magnitude of this problem is unknown and the existance of this problem has not been proven.

Trend Monitoring

Another type of monitoring that is used for groundwater systems is trend monitoring to determine long-term trends in groundwater quality. These trends may be associated with a particular activity, or may just show natural groundwater quality changes. Practices such as grazing, development of subdivisions, and logging can be monitored to measure long-term trends that may not be specific to a particular subdivision or a particular logged area, but may be regional. For example, in an area that has intensive subdivision activity, such as the Helena valley, or the Ravalli County area, a network of wells can be sampled on a long-term basis for a few selected

parameters to determine comparative water qualities and to determine long-term trends in these parameters. Based on these data, an overall trend to groundwater quality may be determined, but may not be related to a specific subdivision.

Monitoring Strategy

With the exception of long-term trend monitoring, or monitoring of specific pollutants to ensure that they do not move into aquifer systems, the objective of all monitoring should be to develop an understanding of cause and effect relationships between activities and groundwater quality. These data should be used to design systems that would prevent groundwater problems. Monitoring shows what has happened in aquifer systems, and the data describes historical events. The emphasis should be on design, installation, operation, and maintenance of systems that will not pollute groundwater.

The development of priorities for establishing monitoring programs include the following criteria:

Probability of groundwater becoming contaminated;

Number of people affected;

Problems reported to regulatory agencies;

Health hazards should groundwater be polluted;

Need for data to relate specific practices to groundwater quality;

Cost of sufficient monitoring;

Likelihood of improving or correcting the situation;

Impact on surface water quality; and

Impact on wildlife and aquatic organisms.

A monitoring plan should include evaluation of:

The area hydrogeological framework including groundwater movement, geology, and soil conditions;

The chemical and physical characteristics of the contaminant and its potential interactions in the subsurface environment. Some substances interact with earth materials in a variety of ways including absorbtion, precipitation, exchange of ions, or dissolution of other ions.

Man-made factors that influence the hydrogeological situation such as pumpage and disposal of liquid wastes.

These data will provide a basic framework for understanding monitoring needs, locations, and parameters to be measured.

Recommended Monitoring Plan

Groundwater monitoring in Montana should address several problem types to develop an understanding of some problems and their cause and effect relationship. Other monitoring is needed to determine groundwater quality trends, and aquifer protection from pollutants.

1. Cause and Effect Relationships

a. Irrigation

The impact of irrigation including both flood and sprinkler irrigation is poorly known. Areas should be selected where these irrigation systems are present and are using waters of marginal quality. The relationship of irrigation practices and soil salinity should be related to groundwater quality.

b. Dryland farming and regional aquifer systems

This involves selection of an area of dryland farming underlain by a regional aquifer so the relationship between salinity developed from dryland farming and water quality in the regional aquifer can be developed.

c. Rehabilitation of saline seep areas

The mechanism involved in rehabilitation of saline seeps including use of water consuming plants in groundwater recharge areas should be investigated to document recovery of aquifers in existing saline areas. This would provide a needed demonstration of groundwater recovery. Typical saline seeps in various parts of the state should be studied to show the rehabilitation mechanism and effect.

d. Sewage treatment lagoons

Impact of sewage lagoons on groundwater quality is poorly known, particularly the relationship of nitrogenous species in the lagoon and in the underlying aquifer. Lagoons are widely used, and provide an excellent means for waste treatment for small communities. The impact of these facilities on groundwater has not been studied and overall impacts are unknown.

e. Land disposal of sanitary wastes

Land disposal is becoming increasingly more important as a means for disposal of sanitary wastes. The impact of the soil environment on sanitary wastes in a northern climate has not been examined in sufficient detail to predict the overall impacts on groundwater quality.

f. Solid waste areas

Solid waste areas that have the potential for groundwater pollution should be examined to determine if groundwater pollution is occurring. Another important consideration in solid waste disposal areas is the infiltration and development of a body of water in solid waste materials in various climate zones in the state. Design criteria are needed for slope, permeability, and depth of cover to ensure that a land disposal area will not become saturated in the future and produce leachates that may enter the underlying groundwater.

g. Feedlots

Impact of feedlots should be examined to determine impact on groundwater quality.

h. Surface impoundments

Some selected surface impoundments should be examined to determine the change in the hydrological system, as a result of reservoirs, in areas of relatively saline soils; moderate to low precipitation, and relatively high evapotranspiration. This would develop an understanding of the impacts of such impoundments on water systems.

i. Mine tailings, waste dumps and acid mine drainage

Additional site-specific examinations are needed at selected facilities to determine the impact on groundwater. This would provide criteria for determining which of these facilities could be abated or corrected.

2. Protection of Aquifers from Entrance of Contaminants

There are some contaminants that must be excluded from aquifer systems to protect the groundwater quality.

a. Brine pits

Based on existing information, there is a question of leakage of a number of brine pits into shallow aquifers. Additional work is needed at selected brine pits to determine the relationship between leakage soil and subsurface materials at the pit locations. This would provide a criteria for future location of brine pits and determination of which pits need membrane or clay liners.

b. Oil and gas activities

Additional inspection is needed of oil and gas exploration, production and development to determine if these activities are a hazard to groundwater quality. This would involve monitoring of nearby wells

and additional field inspection of facilities.

c. Petroleum storage and transport

An additional inventory is needed of groundwater problems associated with petroleum and transport facilities. An understanding of average life and typical failure of storage tanks is needed. Several thousand tanks presently in the ground will fail in the future. Those areas that are most sensitive to failure should be assessed and a preventive strategy needs to be developed.

d. Waste treatment lagoons and land disposal

Waste treatment lagoons and land disposal areas that are developed in the future need to have monitoring systems to determine the effectiveness of the treatment method to detect and prevent unwanted seepage into groundwater.

e. Solution mining

Monitoring the solution mining of uranium, potash, and potentially gold and copper, is needed in some selected locations. Such monitoring would be on a case-by-case basis and would relate to the sensitivity of the area and other criteria previously discussed for monitoring systems.

3. Trend Monitoring

a. Municipal water supply wells

Municipal water supply wells are required to have a chemical analysis on a periodic basis. They would be a good basis for monitoring long-term trends in groundwater quality in the Statewide 208 Area.

b. Dryland crop areas

Wells should be selected in areas of intensive dryland crop farming to determine if there are long-term salinity trends in these areas.

c. Oil fields

Domestic, stock and municipal wells near oil fields should be selected and monitored to determine if there are long-term trends related to oil field activities, particularly brine disposal and handling.

d. Irrigated areas

The effect of irrigation should be examined by use of a number of wells that would examine the trend in water quality in areas of intense irrigation. This would be particularly important in areas of sprinkler use and in areas that have saline soils or have demonstrated salinity problems.

There is a major need in Montana for a coordinated, well designed long-range monitoring plan that considers all the monitoring needs. This will require a good study design, some test monitoring, a centralized data handling system and adequate funding. Increased groundwater use in the Statewide 208 Area and more intense land and water use, makes groundwater monitoring an important future task.

PRIORITIZATION OF PROBLEMS

A number of activities occurring in the Statewide 208 Area impact groundwater quality. Table 17 relates the specific activities and chemical or physical parameters potentially impacted by these activities. Actual impacts are a result of a complex interrelationship between activities, regulation, enforcement, and environment. Parameters shown on the Table are water quality parameters of importance to health, agricultural and industrial uses, and protection of aquatic life.

The overall importance of a particular activity not only depends on the significance of each individual problem, but on the frequency that the problem occurs. If the activity occurs only in a few places, it may be easy to regulate, focus upon, and understand. There are seven oil refineries in Montana, only one paper mill, and thousands of irrigated farms. Industrial activities involve a significant threat to groundwater in a few concentrated locations whereas agricultural activities, such as dryland and irrigated cropping involve millions of acre-feet of water and affect a signficant portion of the Statewide 208 Area. The overall potential groundwater quality impact, based on the frequency and intensity of activities, is shown on Table 18.

The intensive and extensive properties of groundwater quality are useful to estimating probable impacts of man's activities, but they are by no means the only parameters to be considered in problem prioritization. There are political, economic, and cultural factors that affect the relative importance of groundwater pollution. Criteria useful for determining the priorities of groundwater problems are protection of health and welfare, relative ease of problem prevention, difficulty in problem correction,

economic impact of correction, total area or number of persons affected, economic and environmental benefits and costs of correction. Another factor common to groundwater is that some problems are so poorly understood that the impact is virutally unknown. Municipal lagoons and irrigation are examples of activities with poorly understood relationships to groundwater quality, thus, overall impacts of these activities are not well known. An assessment of problem understanding and an estimation of the potential for prevention, abatement, or correction of groundwater problems is shown in Table 18. In addition to these factors, a number of less tangible but important factors were considered including laws and regulations (including administration and enforcement), financial incentives such as tax subsidies and penalties, and government support payments and lending policies. Other controlling factors include threat of litigation, public education and public opinion. Many of these controlling factors are intertwined to some degree. A good public education program concerning groundwater quality could, for example, encourage farmers to employ better management practices or public opinion related to solid waste disposal could result in new regulations or more enforcement of this activity.

Additional control needs including laws and regulations, public education, financial incentives and administration and enforcement were assessed since these are the major factors in long-term control of groundwater pollution problems.

Prioritization or ranking of problems must relate to an objective. In this report problems are ranked relative to:

1. Magnitude and scope of present groundwater quality problem;
2. Magnitude and scope of future groundwater quality problems;

3. Feasibility of cost effective abatement or correction of existing problems;
4. Feasibility of prevention or minimization of future problems.

Present groundwater quality problems are a product of the significance of each problem and the number of problems present in the Statewide 208 Area (Table 18). Based on this criteria, the following is a ranking of present problems with the most important problem first, and other problems in order of descending importance.

1. Dryland farming
2. Oil production
3. Irrigation (poorly understood)
4. Transport and storage of refined petroleum products
5. Domestic sanitary wastes
6. Municipal sanitary wastes
7. Petroleum exploration and development

The remainder of the activities in the Statewide 208 Area presently have minor impacts on groundwater quality and are not considered to be an existing problem.

In view of the relative small use of groundwater in Montana, and the expected rapid increase in this use, impact of future activities on groundwater quality are of importance. The overall scope and magnitude of future activities in the groundwater 208 area were considered to develop the ranking. The potential future problems are ranked below in descending order of importance:

1. Dryland farming
2. Oil production
3. Irrigation (poorly understood)

4. Transport and storage of petroleum
5. Domestic sanitary wastes
6. Petroleum development
7. Coal strip mining

Other activities within the Statewide 208 Area are considered to have much less significance in the future on groundwater quality.

Another prioritization relative to feasibility of cost effective abatement and correction of existing groundwater quality is of value. As described in this report, groundwater problems commonly are difficult to correct, and cost effective solutions to aquifer damage or groundwater degradation are limited. The only problem that can possibly be corrected or abated in a cost effective manner is saline seep and possibly some tailings and waste dump leachate problems. A review of other groundwater problems indicates that correction or abatement of these problems cannot be done in a cost effective manner. Even saline seep will depend on the relative price of high-water use crops such as alfalfa versus small grains. There must be an economic incentive for farmers to alter their farming operation to avoid saline seep problems. Under current conditions where small grain prices are comparatively low and alfalfa prices are high, it may be economical to correct some dryland farming saline seep problems.

Problems such as gasoline pollution of aquifers can be abated by installing charcoal filters. This, in fact, does not abate the pollution problem, but merely corrects the problem in a specific well. This is not considered a corrective or abatement technique, but is a simple treatment of the symptom rather than the problem.

Another problem in Montana is the feasibility of prevention or minimization of future groundwater problems. Many groundwater problems that exist now will continue to exist. They will pre-empt the use of groundwater and would be economically, politically, and socially difficult to correct. Problems such as seepage of water from sewage treatment lagoons, land disposal of sanitary waste, the effects on groundwater from irrigation, and to some extent from saline seep, and transport and storage of petroleum products will not be prevented, and may not be minimized in the future. Other aspects of groundwater pollution including coal mining, coal conversion, hard rock and open cut mining, mineral concentrating and refining, uranium and potash solution mining, feedlots, and solid waste problems can be prevented in the future by additional technical measures, monitoring and enforcement.

A conclusion of this section is that many major activities that impact groundwater in Montana will be difficult to correct or prevent in the future.

TABLE 17

POTENTIAL GROUNDWATER QUALITY IMPACTS DUE TO VARIOUS ACTIVITIES IN THE STATEWIDE 208 AREA

ACTIVITY (O None, S Small, M Moderate, L Large, V Variable)	Salinity	Nutrients	Metals	pH	Odor, Taste Color	Micro-organisms	Pesticides	Toxic Organics	Groundwater Quantity
OIL AND GAS									
Exploration Development	S	0	S	0	L	0	0	L	0
Production	L	0	S	S	L	0	0	L	L
Refining	M	S	S	S	L	0	0	L	M
Transportation & Storage	S	0	0	0	L	0	0	L	0
COAL									
Mining	M	M	S	M	S	0	0	S	M
Conversion	L	V	S	S	M	0	0	V	S
SOLUTION MINING									
Uranium	L	S	L	L	M	0	0	S	M
Potash	L	L	S	S	S	0	0	0	M
MINING & MINERALS PROCESSING									
Hard rock & open cut mining	V	M	V	V	S	0	0	S	S
Concentrating & refining	L	0	L	L	S	0	0	V	S
Tailings & waste dumps	L	S	L	L	S	0	0	S	S
Leaching	L	S	L	L	M	0	0	L	S

TABLE 17

POTENTIAL GROUNDWATER QUALITY IMPACTS DUE TO VARIOUS ACTIVITIES IN THE STATEWIDE 208 AREA

ACTIVITY (O None, S Small, M Moderate, L Large, V Variable)	Salinity	Nutrients	Metals	pH	Odor, Taste Color	Micro-organisms	Pesticides	Toxic Organics	Groundwater Quantity
AGRICULTURE									
Dryland Farming	L	L	M	M	0	0	S	0	V
Irrigation	V	V	S	0	0	0	S	0	L
Feedlots	M	L	0	M	S	L	S	S	0
FOREST PRODUCTS									
Logging	0	S	0	0	0	0	0	0	S
Sawmills	S	S	0	0	S	0	0	0	0
Plywood & Fiberborad	M	S	S	S	M	0	0	M	S
Paper Products									
SANITARY WASTES									
Municipal Lagoon	M	L	S	S	S	M	S	S	M
Domestic (septic tanks)	S	L	S	S	S	M	S	S	S
Sewage Treatment Plants	S	S	S	S	S	S	S	S	0
Land Disposal & Sewage Effluent	M	L	S	S	M	S	S	S	S
SOLID WASTES	S	S	S	S	S	S	S	S	0
SURFACE IMPOUNDMENTS	V	S	0	0	0	0	0	0	V

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TABLE 18

SUMMARY OF GROUNDWATER POLLUTION POTENTIAL, CONTROL AND NEEDS IN THE STATEWIDE 208 AREA

ENVIRONMENTAL ACTIVITY	NUMBER OF OCCURRENCES	Reported pollution problem	Groundwater impact/occurrence	Overall potential impact	Problem understanding	Research & develoment needs	Existing Controls: Laws & regulations	Existing Controls: Enforcement	Existing Controls: Litigation	Existing Controls: Public education	Existing Controls: Public opinion	Existing Controls: Financial incentives*	Prevention potential	Abatement correction potential	Additional Control Needs: Laws & regulations	Additional Control Needs: Enforcement	Additional Control Needs: Public Education	Additional Control Needs: Financial Incentives*
OIL AND GAS																		
Exploration & Development	10,000 seismic holes/yr 700 wells/yr	Few	M	S-M	P	M	P	P	F	P	G	P	G	P	M	M	M	S
Production	3,400 wells	Few	S-L	M-L	P	M	P-F	P-F	P	M	G	P	F-G	P	M	M	M	S
Refining	4 oil 4 condensate	None	S	S	M	S	P-F	F	M	M	G	P	G	F	S-M	S	S	S
Transport & Storage	3,500 miles pipe 3,000 underground tanks	Many	M	M	G	M	P-F	F	M	M	M	P	F	P	S-M	M	M	S
COAL																		
Mining	3 mines	None	M	M	M	M	G	G	G	G	G	P	F	P	S	S	M	S
Conversion	50 MW steam electric	None	S	S	M	S	P-F	F	G	M	G	P	G	P	S-M	S	M	S
SOLUTION MINING																		
Uranium	None	None	M	S	M	M	P	N/A	M	P	M	P	G	P-F	L	N/A	M	S
Potash	None	None	L	S	M	M	P	N/A	M	P	M	P	G	P-F	M	N/A	M	S
MINING & MINERAL PROC.																		
Hard Rock & Open Cut Min.	64	Few	S-M	S	M	M	F-G	F-G	M	M	G	P	G	P-F	S-M	S-M	S	M
Concentration & Refining	7 concentrating 5 refining	Few	S-M	S	P	S	F	F	[illegible]	M	G	P	G	G	M	S	S	S
Tailings & Waste Dumps	Many	Many	S-M	S-M	M	S-M	P-F	P-F	M	P	M	P	F-G	P-F	M	S-M	M	M
Leaching	1 acid 7 cyanide	1	S-L	S-M	F	M	F	F	G	P	G	P	G	M	M	M	M	S

*Financial control may involve grants, tax incentives, loans, and other means of financing

G - Good   L - Large   N/A - Not applicable

F - Fair   S - Small   U - Unknown

P - Poor   M - Medium   V - Variable

TABLE 18 (Cont)

SUMMARY OF GROUNOWATER POLLUTION POTENTIAL, CONTROL ANO NEEOS IN THE STATEWIOE 208 AREA

ENVIRONMENTAL ACTIVITY	NUMBER OF OCCURRENCES	Reported pollution problem	Groundwater impact/occurrence	Overall potential impact	Problem understanding	Research & development needs	Existing Controls: Laws & regulations	Enforcement	Litigation	Public education	Public opinion	Financial incentives*	Prevention potential	Abatement correction potential	Additional Control Needs: Laws & regulations	Enforcement	Public Education	Financial incentives*
AGRICULTURE																		
Oryland Farming	11 million acres	Many	S-L	L	G	L	P-F	P	P	P-F	P	P	P-F	P-F	M	M	L	L
Irrigation	1 million acres	Few	U	L	P	L	P	P	P	P	P	P	P	P	M	M	L	L
Feedlots	175	Few	S	S	M	S-M	P-F	P-F	P	P	P-F	P	G	F	S-M	S-M	M	M
FOREST PRODUCTS																		
Logging	150,000 acres/yr	None	S	S	P-F	S	P	N/A	P	P	P	P	P	P	S	S	S	M
Sawmills	120-215	None	S	S	G	S	P-F	N/A	F	P	P	P	F	F	S	S	S	P
Plywood & Fiberboard	5	One	S	S	G	S	P-F	P-F	G	F	G	P	G	S	S	S	S	P
Paper Products	1	One	L	S	G	S	P-F	P-F	G	G	G	P-F	G	S	S	S	S	P
SANITARY WASTES																		
Municipal Lagoon	100	Few	M	S	P	L	P-F	P	F	P	F	G	F-G	F-G	S	S	S	L
Oomestic	Over 10,000	Few	S	S	M	M	P-F	P	P	P	F	P	F-G	P-F	S-M	S-M	P	M
Sewage Treatment Plants	20	None	S	S	G	S	P-F	N/A	F	P	F	G	G	F-G	S	S	S	L
Land Oisposal of Sewage	Few	None	M	S	M	M	P-F	N/A	F	P	G	M	G	F	S	S-M	M	M
SOLIO WASTES	203 sites	Few	S-M	S	F	M	G	G	F	P	G	G	G	F	S	S	S	M
SURFACE IMPOUNOMENTS	Over 1,000 (900,000 acres)	Few	S-M	S	P	M	P	P	P	P	P	P	P	P-F	S	S-M	M	M

*Financial control may involve grants, tax incentives, loans, and other means of financing

G - Good L - Large N/A - Not applicable

F - Fair S - Small U - Unknown

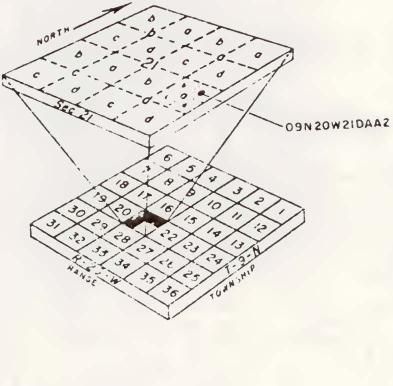
P - Poor M - Medium V - Variable

Appendices

APPENDIX I

SYSTEM F[illegible]ATION OF FEATURES

Wells, springs, water-sampling locations, and stream-gaging locations are assigned numbers based on the system of land subdivision used by the U. S. Bureau of Land Management. The number consists of twelve characters and describes the location by township, range, section, and position within the section. The figure below illustrates the numbering method. The first three characters of the number give the township, the next three characters the range. The next two numbers give the section number within the township, and the next three letters describe the location within the quarter section (160-acre tract) and the quarter-quarter section (40-acre tract), and the quarter-quarter-quarter section (10-acre tract). These subdivisions of the 640-acre section are designated a, b, c, and d in a counterclockwise direction, beginning in the northeast quadrant. If there is more than one feature in a 10-acre tract, consecutive digits beginning with 2 are added to the number. For example, if a water-quality sample was collected in sec.21,T.9N.,R20W, it would be numbered 09N20W21DAA2. The letters DAA indicate that the well is in the NE¼ of the NE¼ of the SE¼, and the number 2 following the letters DAA indicates there is more than one water quality sampling location in [illegible] tract.



APPENDIX II An Assessment of Water Quality Data From Municipal Water Supplies in the Statewide 208 Area

City Or Town	Water Supply Source		Parameters Violated					
	Surface	Ground	TDS	Sulfate	Iron	Fluoride	Nitrate	Other
Alberton		X						
Anaconda	X	X						
Babb		X	X	X				
Bainville		X	X	X				
Basin	X							
Belt		X	X				X	
Big Sandy		X	X	X	X		X	Na Cl
Boulder		X						
Boulder (State)		X						
Brady	X							
Brockton		X	X					
Browning		X						
Butte	X							Cu
Canyon Ferry								Cu
Cascade		X						
Chester	X							
Chinook	X							
Choteau		X						
Circle		X						Na
Clancy		X						Cu
Coffee Creek		X	X				X	Pb
Conrad	X				X			

City Or Town	Water Supply Source		Parameters Violated					
	Surface	Ground	TDS	Sulfate	Iron	Fluoride	Nitrate	Other
Cooke City		X						
Culbertson	X				X			
Cut Bank								
Cut Bank (WESCO)		X	X		X			
Darby		X						
Deer Lodge	X	X						
Deer Lodge (State)	X	X						
Denton		X					X	
Devon		X	X	X				
Dillon	X	X	X (GW)	X (GW)				
Dodson		X	X	X				
Dutton		X	X	X				
East Helena	X	X						
Ennis		X						Pb
Eureka	X	X						
Eureka (Midvale)		X						
Fairfield		X						
Fairview		X	X	X	X			
Flaxville		X	X				X	Cl
Fort Benton	X				X			
Fort Harrison		X						
Fort Peck	X							
Fortine	X							
Frazer		X	X	X				Na
Galen		X						

City Or Town	Water Supply Source		Parameters Violated					
	Surface	Ground	TDS	Sulfate	Iron	Fluoride	Nitrate	Other
Gardiner	X	X						
Geraldine		X	X	X	X	X		
Geyser		X	X	X				
Glasgow		X	X	X				Cl
Glasgow (AVCO)	X							
Glendive	X		X					
Glendive (Highland Park)		X	X					
Great Falls	X							
Hamilton		X						
Harlem	X							
Harlowton		X	X	X	X	X		
Havre	X	X	X (GW)	X (GW)		X		
Helena	X							
Helena (State)		X						
Heron		X						
Highwood		X						
Hill Co. Water District	X							
Hinsdale		X	X	X				
Hot Springs	X	X						
Jordon		X	X	X				
Judith Gap		X	X	X				
Kevin		X	X		X			
Lambert		X	X	X				
Lewistown		X						
Libby	X							

City Or Town	Water Supply Source		Parameters Violated					
	Surface	Ground	TDS	Sulfate	Iron	Fluoride	Nitrate	Other
Libby (Pinewood)								
Lima		X						
Livingston	X	X						
Malta		X	X	X	X			
Martinsdale		X						
Medicine Lake		X	X	X				
Melstone		X	X	X				
Missoula	X	X						
Missoula (Hillview Heights)		X						
Moore		X						
Musselshell		X	X	X				
Nashua		X	X	X	X			
Neihart	X							
Noxon	X							
Noxon (WWP)		X						
Opheim		X						
Paradise		X			X			
Philipsburg	X				X			
Plains		X						
Plentywood		X	X	X	X			
Poplar		X	X					
Power	X		X	X				
Ramsay		X						
Rexford	X							
Richey		X	X			X		
Rocky Boy		X						

City Or Town	Water Supply Source		Parameters Violated					
	Surface	Ground	TDS	Sulfate	Iron	Fluoride	Nitrate	Other
Round Butte		X						
Roundup		X	X	X	X			
Ryegate		X	X	X				
Saco		X	X	X				Na
Sand Coulee		X			X			
Scobey		X	X	X	X			
Shelby		X			X			
Sheridan		X						
Sidney		X	X	X	X			
Silver Gate		X						
Square Butte		X						
Stanford		X	X					
Stevensville	X	X						
Stockett		X						
Summit		X						
Sunburst		X	X	X				Na
Superior		X						
Thompson Falls	X	X						
Thompson Falls (Woolin)		X						
Three Forks		X	X					
Townsend		X						
Tracy		X						
Trident		X						
Trout Creek		X						
Troy	X	X						
Twin Bridges		X						
Twin Bridges (State)		X						

City Or Town	Water Supply Source		Parameters Violated					
	Surface	Ground	TDS	Sulfate	Iron	Fluoride	Nitrate	Other
Valier		X	X					
Vaughn		X	X	X				
Virginia City		X						
Warm Springs		X	X					
Westby		X	X	X				
Whitehall		X	X	X	X			Cl
Wibaux		X	X	X				Na
Wilsall		X						
Winnett		X	X	X	X			
Wolf Point		X	X	X	X			

APPENDIX III. Brine Disposal and Secondary Recovery

* Average Monthly for January through June, 1977
\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Arch Apex	Toole			4	119	-				
Bainville	Roosevelt	Red River		1	99,449	1,592				Disposal
Bainville	Roosevelt	Red River		1			20,127	820		
Bears Den	Liberty	Sunburst		5		772				
Benrud	Roosevelt			1	137,330	4,233				
E. Benrud	Roosevelt	Nisku	Frank Pet. Murphy Big Track Little	3		27,434				
E. Benrud	Roosevelt	Judith R.	Frank Pet. Murphy Big Track Little	3			2,518,581	27,500		Disposal
N.E. Benrud	Roosevelt	Nisku		1		13,892				
N.E. Benrud	Roosevelt	Judith R.	Murphy	1			1,367,186	13,892		Disposal
Big Gully	Musselshell	Tyler	Petro Lewis	2	3,326	245				
Big Muddy	Roosevelt	Interlake		1	50,873					
Big Muddy Creek	Roosevelt	Red River		4	16,559	1,191				

* Average Monthly for January through June, 1977
+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Big Wall	Musselshell	Amsden		1		35,038				
Big Wall	Musselshell	Upper Tyler A	Texaco	2			18,997,187	155,085	1267	Sec. reco
Big Wall	Musselshell	Tyler		6		17,314				
Big Wall	Musselshell	Tyler B		7-8	9,660,206	106,060				Productio brine to injection
Blackfoot	Glacier	Cut Bank Madison		7		3,868				
Blackfoot	Glacier	Cut Bank Sand.	Craft Pet.	2			90,201	11,226	2620	Sec. reco
New Border	Toole	Sunburst		2						
New Border	Toole	Sunburst	B.G.& O.	1			256,911	4,115	2000	Sec. reco
Old Border	Toole	Sunburst		5						
Old Border	Toole	Sunburst	B.G.& O.	4			694,304	11,948	2600	Sec. reco
Border	Toole	Sunburst	Discovery Alaska Kenai	1-3						
Boulder	Richland	Red River		1						
Bowes	Blaine	Sawtooth	Texaco	4			7,653,462	22,040	1400	Sec. reco

* Average Monthly for January through June, 1977
\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Bowes	Blaine	Sawtooth		51-56				22,040		5,717,725 produced prior to injection
Breed Cr.	Roosevelt	Tyler		2-5						
Brarson	Richland	Madison		5		448				
Brarson	Richland	Red River		4		1,392				
So. Brarson	Richland	Red River		3		711				
Brush Lake	Sheridan	Red River		5		9,652				
Brush Lake	Sheridan	Dakota					873,142	4,711		Disposal
Burns Creek	Dawson	Red River		1	84,615	530				
Canal	Richland	Red River		1	8,825	51				
Cat Creek	Petroleum	Amsden		2	2,209	253				
Mosby Dave	Petroleum	Amsden		1			105,924	3,825	1465	Sec. reco
Cat Cr. #1	Petroleum			17		69,739				
Cat Cr. #1	Petroleum	1st & 2nd Cat Creek		7			11,377,495	55,335	855	Sec. reco
Cat Cr. #2	Petroleum	2nd Cat Creek		10		17,724				

* Average Monthly for January through June, 1977
\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Cat Creek	Petroleum	1st and 2nd Cat Creek		6			17,927,146	30,278	842	Sec. reco
Cat Creek East Dome	Garfield	Ellis		10-12		3,012				
Cat Creek East Dome	Garfield	Ellis		4			412,007	7,255	1151	Sec. reco
Mosby Dome	Petroleum	Swift		8	2,652,464	29,303				
Mosby Dome	Petroleum	Swift		4			4,034,894	34,469	872	Sec. reco
Cat Creek Total	Petroleum Garfield			44-59		138,810				Amsden no included
Charlie Cr.	Richland	Nisku		1-2	116	24				
Cow Creek	McCone	Charles		2	283,659	2,856				
E. Cow Cr.	McCone	Kibby		10	1,506,270	47,888				
Cow Creek	McCone	Dakota		2			845,381	47,091	1211	Disposal
Culbertson	Roosevelt	Red River		1	105,175	1,113				
Cut Bank	Glacier - Toole	Total Prod -including Madison		841-915						

* Average Monthly for January through June, 1977
\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Cut Bank	Glacier	Cut Bank	B.G.& O.	6-7						Marina W.C Sand U
N. Cut Bank	Toole	Madison	Bexen, Texaco, Texa, Union	28		35,198				
Cut Bank		Lander Sand	Phillips Tribal A	6		8,415				
Cut Bank		Lander Sand	Phillips Lander A	1		2,913				
Cut Bank	Glacier	Cut Bank	Phillips	104	480	65				N.C.B. Sa Unit
Cut Bank		Lander Sand	Texaco	4		47,736				
Cut Bank	Glacier Toole	Moulton	Union	2	3,862,258	28,796				McGinnas
Cut Bank		Cut Bank	Union	107-123		24,940				S. Centra
Cut Bank			Texaco	70		2,906				N.E.C.B. Unit
Cut Bank		Cut Bank	Texaco	52		182,117				S.E.C.B.
Cut Bank		Cut Bank	Phillips	16		7,980				N.W.C.B.
S.W. Cut Bank			Miami	184	13,143,952	117,384				Miami Twc Unit

* Average Monthly for January through June, 1977
\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Cut Bank M. Unit		Moulton	Montana Power	8		9				
Cut Bank	Toole	Moulton	Union	5		9,663				
S.W. Cut Bank	Glacier	Cut Bank	Texaco	29		29,634				C.B. Sand Unit
Cut Bank	Glacier	Cut Bank	B.G.O.	9						Tweedy S. Unit
Cut Bank			Phillips	190		394,395				S.W.C.B.
C.B. N. Darling	Toole	Moulton	B.G.& O.	1		2,122				N. Darlin Moulton S Unit
C.B. Darling	Toole	Moulton		7		33,440				Ralph Fai N.E. Unit
C.B. Darling	Glacier	Moulton	B.G.& O.	7		5,490				S. Darlin Swenson
Cut Bank	Glacier	Madison		1			269,074	14,819		Disposal Kruger F.
N. Cut Bank	Glacier	Madison		1			210,390	6,593		Gorman, d
Cut Bank	Glacier	Cut Bank	B.G.& O.	8			1,796,268	20,499	2122	Sec. reco Marina W. Unit

* Average Monthly for January through June, 1977
\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Cut Bank	Glacier	Lander Sand.	Phillips Lander A	2			1,502,607	4,544	2000	Sec. reco\
Cut Bank	Glacier	Lander Sand.	Texaco	5			7,655,023	45,466	2567	Tex. Lande Rasmussen Sec. reco\
Cut Bank	Glacier	Madison	Union	1			4,178,859	28,796	296	McGinnis S recovery
S. Central Cut Bank	Glacier	Cut Bank		39			33,182,582	185,098	2952	Sec. reco\
N.E. Cut Bank	Glacier	Cut Bank	Texaco	6			13,292,883	9,647	1784	Fee M 422 sec. reco\
S.E. Cut Bank	Glacier	Cut Bank	Texaco	50			53,523,128	243,708	2878	M 455 sec. recovery
S.W. Cut Bank	Glacier	Cut Bank	Phillips	89			79,270,106	536,824	2742	Sec. reco\
N.W. Cut Bank	Glacier	Cut Bank	Phillips	15			15,307,018	51,151	2500	Sec. reco\
S. Cut Bank	Toole	Cut Bank	Miami	72			41,319,659	117,027	2100	Two Medic Sec. Reco\
Cut Bank	Glacier	Cut Bank	B.G.& O.	3			833,379	4,826	2670	Tweedy S.(Sd. U. se(recovery

* Average Monthly for January through June, 1977
\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Cut Bank	Glacier	Lower Cut Bank	Texaco	20			3,677,326	55,240	581	C.B. Sand. Sec. reco
C.B. Darling Moulton	Toole	Moulton	B.G.& O.	2			2,474,209	2,315	1084	State 5N Darling S recovery
Cut Bank	Toole	Moulton		4			5,004,336	37,241	1900	Ralph Fai N.E. Darl
Cut Bank S. Darling	Toole	Moulton	B.G.& O.	3			7,420,224	9,338	1013	State-Var Swenson
Cut Bank Moulton	Toole	Moulton	Union	6			16,299,183	77,793	2008	Sec. reco
Dagmar	Sheridan	Ratcliffe		2	3,194	1,597				
Deer Creek	Dawson	Interlake		1		1,496				
Deer Creek	Dawson	Dakota					1,999,426	1,497	1300	Disposal
Delphia	Musselshell	Amsden		1						
Dwyer	Sheridan	Ratcliffe	Monsanto Hunt	1		7,491				
Dwyer	Sheridan	Ratcliffe		9		7,961				
Dwyer	Sheridan	Ratcliffe	Phillips	5			1,599,414	18,704	1006	Sec. reco
Fairview	Richland	Winnepegosis	Superior	1		1,997		[illegible]		Vanderhof Sec. reco

* Average Monthly for January through June, 1977
\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
N.W. Fair-view	Richland	Red River		5		5,220				
N.W. Fair-vies	Richland	Red River		1			Gas 3,055,542	Gas 33,142	Gas 2700	Sec. reco
Fairview	Richland	Red River		3		1,707				Non Unit
Fairview	Richland	Dakota	Tenneco	1			306,155	1,451	100	Disposal
Flat Coulee	Liberty	Swift		16		5,445				
Flat Coulee	Liberty	Swift		5						Non Unit
Flat Coulee	Liberty	Swift		15			3,881,821	59,391	2608	Sec. reco
Flat Lake	Sheridan	Ratcliffe		49		90,833				Total Oil
Flat Lake	Sheridan	Ratcliffe		35		69,048				
Flat Lake	Sheridan	Ratcliffe		3		7,748				Non Unit
S. Flat Lake	Sheridan	Ratcliffe		5		7,382				
W. Flat Lake	Sheridan	Ratcliffe		11	476,792	14,038				
Flat Lake	Sheridan	Dakota		1			3,919,665	6,681		Disposal

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\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Flat Lake	Sheridan	Ratcliffe		11			13,881,941	174,617		Sec. recc
Fort Gilbert	Richland	Red River		2	89,024	3,102				
Four Mile Creek	Richland	Red River		1						
Fred & George	Toole		Fulton	30		169,862				Total Pro
Fred & George	Toole	Sunburst		13		174,904				Wm Filton Sunburst
Fred & George	Toole	Sunburst A	Fulton	2			16,446,563	217,751		Sec. reco
S. Froid	Roosevelt	Red River		1	186,124	2,582				
Gage	Musselshell	Amsden		1						
Gas City	Dawson	Red River		16		50,646				
Gas City	Dawson	Red River		8			9,124,528	104,132	2400	Sec. reco'
Gas City	Dawson	Judith R.	Shell	2			5,033,847	14,996	871	Disposal
Girard	Richland	Red River		1		2,885				
Glendive	Dawson	Story Mtn.		16		75,841				
Glendive	Dawson	Swift	Shell	2			2,122,264	10,757	1375	Disposal

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\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Glendive	Dawson	Dakota	Texaco	1			10,737,631	61,892	1700	State-D Disposal
Goose Lake	Sheridan	Ratcliffe		19		110,941				Total pro(
N. Goose Lake	Sheridan	Ratcliffe		6	4,858,924	30,149				
Goose Lake	Sheridan	Dakota	Colton	2			15,649,360	51,250	100	Disposal
Goose Lake	Sheridan	Dakota	Saratoga	1			1,009,486	7,679	300	Disposal
Goose Lake	Sheridan	Dakota	Cattol	1			2,636,863	2,602		Disposal
N. Goose Lake	Sheridan	Ratcliffe		4			5,080,222	62,301	1132	Sec. reco'
Graben Coulee	Glacier	Madison Cut Bank		38						
Gypsy Basin	Pondera Teton			8	3,738	156				
Hay Creek	Richland	Mission Canyon	Consolidated	1	204,201	2,085				
Hay Creek	Richland	Red River		3	126,393	1,723				
Hay Lake	Glacier	Madison		1				6,886		Disposal
Hiawatha	Musselshell	Tyler B		4		14,898				
Hiawatha	Musselshell	Tyler Steusvad		1			1,286,550	15,439	804	Disposal

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\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Horse Creek	Liberty	Swift		1	1,162	105				
Howard Coulee	Musselshell	Tyler A		2		3,581				
Ivanhoe	Musselshell	Morrison	Champion Mobil	1		193				
Ivanhoe	Musselshell	Tyler B		9		3,644				
Jim Coulee	Musselshell	Tyler		16	1,728,433	56,686				
N. Jim Coulee	Musselshell	Tyler		1	255,351	1,455				
Jim Coulee	Musselshell	Tyler		5			5,549,916	112,230	2242	Sec. reco
Keg Coulee	Musselshell	Tyler	Conoco	8		4,497				
W. Keg Coulee	Musselshell	Tyler	Ada	3		9.186				
Keg Coulee	Musselshell	Tyler	B.G.& O.	8		9,922				
Keg Coulee	Musselshell	Tyler	Exeter	4	345,282	20,938				
N. Keg Coulee	Musselshell	Tyler	Phillips	2	52,534	1,198				
N.W. Keg Coulee	Musselshell	Tyler	Ada	1			5,127,112	12,267	1300	Sec. reco

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\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Long Creek	Roosevelt	Charles C.	Pennzoil	1	16,394	650				
W. Long Cr.	Roosevelt	Nisku	Pennzoil		9,530	1,906				
Mason Lk.	Musselshell	3rd Cat Creek		2		5,862				
Melstone	Musselshell	Tyler		4		15,373				
Mineral Bench	Roosevelt	Charles C.		1		5,200				
Mineral Bench	Roosevelt	Dakota		1			630,260	4,925	43	Disposal
Miners Coulee	Toole	Swift-Sunburst		5						
Mon Dak W.	Richland	Red River	Shell	3	20,070	854				
Nohly	Richland	Red River		2	4,250	91				
North Fork	Richland	Red River	Pennzoil	1	35,790	2,094				
Otis Cr.	Richland	Red River		2	91,302	1,368				
S. Otis Cr.	Richland	Red River		2	135,417	2,229				
Outlook	Sheridan	Duperow		1		38,375				
Outlook	Sheridan	Silo-Oro.		4		29,370				
Outlook	Sheridan	Winnipegosis		3		43,396				

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Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
E. Keg Coulee	Musselshell	Tyler A-C	Conoco	2			3,502,148	6,505	1792	Sec. reco
Keg Coulee	Musselshell	Tyler	B.G.& O.	2			2,463,515	33,531	1785	Sec. reco
Kelley	Musselshell	Tyler B		3		21,252				
Kelley	Musselshell	Tyler					2,093,083	31,049	654	Sec. reco
Kevin Sunburst	Toole	Madison Sunburst		562						
Kevin Sunburst	Toole	Sunburst	B.G.& O.	24		17,986				
Kevin Sunburst	Toole	Sunburst	Texaco	11		18,735				
Kevin Sunburst	Toole	Sunburst	B.G.&. O.	9			6,038,588	66,539	1650	Sec. reco
Kevin Sunburst	Toole	Sunburst	Texaco	10			9,018,157	32,472	2260	Sec. reco
Laird Creek	Liberty	Swift		10		35				
Laird Creek	Liberty	Swift		3			106,387	21,277	2260	Sec. reco
Little Wall	Musselshell	Tyler		13	322,053	6,962				
Lone Butte	Richland	Red River	U.V.	2	71,922	3,296				
Lone Tree Creek	Richland	Red River		7	114,692	1,754				

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\+ Cumulative through June, 1977

Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
S. Outlook	Sheridan	Silo-Oro		1	1,226,032	40,533				
W. Outlook	Sheridan	Winnipegosis		2		13,501				
Outlook	Sheridan	Dakota-New Castle		1			15,724,111	45,346		Disposal
Outlook	Sheridan	Silurian		1			3,861,858	65,796		Disposal
S. Outlook	Sheridan	Dakota		1			3,720,405	40,533		Disposal
W. Outlook	Sheridan	Dakota		1			1,372,701	13,501	400	Disposal
Pine A & E Unit	Fallon Dawson	Siluro-Oro		35			142,667,962	760,715	2525	Sec. reco
Pondera	Pondera	Sun River		321						
Pondera	Teton	Madison	Phillips Rocky Mtn.	7			19,462,323	102,971		Brine Disposal
S.E. Poplar	Roosevelt	Charles C		1		32,051				
E. Poplar	Roosevelt	Heath	Polumbus Murphy	3		17,425				
E. Poplar	Roosevelt	Nisku	Polumbus	1		54,690				
E. Poplar	Roosevelt	Charles	Murphy	59		798,288				
N.W. Poplar	Roosevelt	Madison		12		24,256				

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Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Poplar	Roosevelt	Judith River		1			1,998,965	32,051	460	Disposal
E. Poplar	Roosevelt	Judity River	Buck Elk	1			3,087,963	13,488	425	Disposal
E. Poplar	Roosevelt	L. Mission Canyon	E.P.U.	1			3,527,987	79,585	500	Disposal
E. Poplar	Roosevelt	Dakota	Murphy	4			99,554,995	730,195		Disposal
N.W. Poplar	Roosevelt	Dakota	Goings	1			33,622	16,811		Disposal
Prichard Creek	Toole	Sunburst		5		1,208				
Prichard Creek	Toole	Sunburst	Fulton	1			268,191	906	1423	Sec. reco
Putnam	Richland	Red River		1	69,596	966				
Putnam	Richland	Silurian		1	356,509	780				
Putnam	Richland	Muddy		1			261,885	4,782	245	Disposal
Rabbit Hills	Blaine	Sawtooth		4	464,848	4,058				
Rabbit Hills	Blaine	Eagle		1			273,484	13,941		Disposal
Ragged Point	Musselshell	Tyler A		24		30,402				

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Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Ragged Point	Musselshell	Tyler A	B.G.& O	9		29,591				
Ragged Point	Musselshell	Tyler A	B.G.& O	5			6,683,987	42,543	1378	Sec. rec
Rattlesnake Coulee	Toole	Sunburst	Phillips Wilco	2						
Raymond	Sheridan	Duperow		1	105,919	2,814				
Raymond	Sheridan	Nisku		2	18,599	5,182				
Raymond	Sheridan	Red River		1						
Raymond	Sheridan	Winnipegosis		3	212,601	6,517				
N.E. Raymond	Sheridan	Red River		1	72,790	4,033				
N.E. Raymond	Sheridan	Winnipegosis		1	136,125	1,693				
N.E. Raymond	Sheridan	Dakota		1			384,249	13,596	1275	Disposal
Reagan	Glacier	Madison		54		25,175				
Reagan	Glacier	Madison		4			970,326	20,889	1026	Sec. reco
Reagan	Glacier	Madison	Union	2			Gas 4,625,680	Gas 14,688	Gas 934	Gas Sec. reco
Reagan Dome	Glacier	Madison		4			950,307	21,063	985	Disposal
Red Creek	Toole	Cut Bank Sand. Unit		7		14,059				
Red Creek	Toole	Madison		12		105,307				

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Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Red Creek	Clacier	Cut Bank	Exxon	5			11,202,731	81,086	2300	Sec. reco
Red Creek	Glacier	Madison		1			3,568,630	15,497	1800	Disposal
Red Fox	Roosevelt	Nisku		1		7,752				
Redstone	Sheridan	Winnipegosis	Hunt			1,025				
Reserve	Sheridan	Red River		3		17,550				
Reserve	Sheridan	Dakota		1			2,683,876	14,764	393	Disposal
Richey	McCone	Charles		3		50,167				
S.W. Richey	McCone			5		6,885				
Richey	McCone	Lakota-Third Co.		1			1,637,068	91,667	400	Disposal
S.W. Richey	McCone	Dawson Bay		1			2,276,461	7,667		Sec. Reco
Ripdrap Coulee	Roosevelt	Ratcliffe	Hel. & Payne	2	20,232	398				
Rush Mtn.	Sheridan	Red River		1	50,186	110				
Salt Lake	Sheridan	Nisku		3		868				
Sand Cr.	Dawson	Red River		5		11,243				
Sand Cr.	Dawson	Swift-Dakota		1			4,179,559	11,243	1400	Disposal
Sec. Cr.	Richalnd	Red River		4	122,328	3,356				
Sheepherder	Musselshell	Tyler C		3	146	7				

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Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Sidney	Richland			4						
Sioux Pass	Richland	Silo-Ord		7	661,697	962,159				
Sioux Pass	Richland	Mission Canyon		1	34,283	1,675				
Middle Sioux Pass	Richland	Red River	Luff-McGinnis	2						
North Sioux Pass	Richland	Silo-Ord		6	282,849	8,114				
Sioux Pass	Richland	Dakota		1			317,526	4,253	250	Disposal
South Fork	Richland	Red River		1	1,212	88				
Spring Lake	Richland	Red River		2		509				
Stensvad	Rose-Bud Musselshell	Tyler B		4		62,176				
Tegen Ridge	Blaine	Eagle	Northern Natural Gas	1						Disposal
Teger Ridge	Hill	Eagle	Tricentral	2			68,676	1,689	350	Disposal
Tule Cr.	Roosevelt	Nisku		5		45,150				
E. Tule Cr.	Roosevelt	Nisku	Bridges-Lillian	2		14,988				
So. Tule Cr.	Roosevelt	Nisku	Brinkerhoff	3		28,227				

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Field	County	Formation	Operator	Number of Wells	Water Production Cumulative+	Water Production Average*	Water Injection Cumulative+	Water Injection Average*	Average Injection Pressure PSIG	Comments
Tule Cr.	Roosevelt	Dakota	Sledvaldt	1			5,220,832	32,600		Disposal
Tule Cr.	Roosevelt	Judity Rv.	Placid	1			2,853,288	18,921	683	Disposal
E. Tule Cr.	Roosevelt	Judith Rv.	Murphy-Bridges-Lillian	1			2,020,103	14,988		Disposal
So. Tule Cr.	Roosevelt	Judith Rv.	Strausser, Boxer	1			964,426	15,903		Disposal
So. Tule Cr.	Roosevelt	Dakota	Brinkerhoff	1			1,412,167	12,294		Disposal
Utopia	Liberty	Swift		4		12,065				
Vaux	Richland	Red River		2	10,080	1,133				
Vida	McCone	Interlake		2		384				
Vida	McCone	Lakota		1			442,204	384	20	Disposal
Volt	Roosevelt	Charles C	Trimble	1		1,939				
Volt	Roosevelt	Nisku		5		40,653				
Volt	Roosevelt	Judith Rv.	Kerkwood-Carleon	1			131,117	6,053	400	Disposal
Volt	Roosevelt	Judith Rv.	Murphy Couchenne	1			5,734,800	36,540		Disposal
Wagon Bos	Musselshell	Tyler A		3	3, 104	48				

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Weldon	McCone	Kibbey		3		126,530				
Weldon	McCone	Lakota	Gulf	1			3,283,236	60,000	1150	Disposal
Weldon	McCone	Dakota	Sinclair-Tait	1			10,547,107			Disposal
Weldon	McCone	Morrison	Sinclair	1			6,226,537			Disposal
Weldon	McCone	Kibbey		1			1,571,958	72,503		Disposal
W. Butte	Toole	Sunburst		1						
Whitlash	Liberty			63						Total Pro
No. Willow Creek	Musselshell	Tyler B			38,290	648				
No. Willow Creek	Musselshell	Tyler		1			120,054			Sec. reco
Willow Ridge	Toole	Dunwash	Croft	1		379				
Winnet Junction	Musselshell	Tyler B		6	649,752	13,808				
Woodrow	Dawson	Total Prod.		2		3,608				Total Pro
Woodrow	Dawson	Dakota	Texaco	1			1,488,062	3,698	1083	Disposal

APPENDIX V

LIST OF CONTACTS

Ken Knudson	Montana Department of Fish and Game, Helena, Montana
Stan Lane	Manager, American Smelting and Refining Co., East Helena, Montana
Mike Jackson	Extension Service, MSU, Bozeman, Montana
Jerry Thorston	U.S. Crop and Livestock Reporting Service Helena, Montana
Lee Pauli	USGS, Conservation Division, Billings, Montana
Judson Sweet	Petroleum Engineer, Montana Oil and Gas Commission Billings, Montana
Marvin Miller	Montana Bureau of Mines and Geology, Butte, Montana
Joe Morreland	USGS, Helena, Montana
Dennis Gray	Idaho Statewide 208 Area, Boise, Idaho
Al Keppner	Montana Subdivision Bureau, Helena, Montana
Ray Chorik	Montana Testing Laboratories, Great Falls, Montana
John Moncreif	Soils Department University of Wisconsin, Madison, Wisconsin
Earl Wohlfrom	ASCS, Helena, Montana
Fritz Schwendt	North Dakota Water Quality Bureau, Bismarck, North Dakota
Merlin Archibald	U.S. Bureau of Reclamation, Billings, Montana
Hayden Ferguson	MSU, Bozeman, Montana
Larry Week	Hoerner-Waldorf, Missoula, Montana
	Lewis and Clark County Fire Department, Helena, Montana

SOIL CONSERVATION SERVICE

Wally Jolly

Mike Carlson

Carl Horner

AGRICULTURAL EXPERIMENT STATIONS

Don Graham	Corvallis, Oregon
Jim Simms	Bozeman, Montana
Leroy Baker	Bozeman, Montana
Pete Fay	Bozeman, Montana
Vince Haby	Huntly, Montana
Harold Houlton	Havre, Montana
Rick White	Miles City, Montana

AGRICULTURAL RESEARCH STATIONS

Art Dubbs	Mocassin, Montana
Paul Brown	Fort Benton, Montana

MONTANA DEPARTMENT OF AGRICULTURE, HELENA, MT.

Roy Bjornson

Gary Gingery

WATER QUALITY BUREAU, HELENA, MT.

Fred Shewman

Dick Pedersen

Dick Karp

Jim Brown

Kevin Keena

Dick Montgomery

Kit Walther

SOLID WASTE BUREAU, HELENA, MT.

Pat Tresler

Roger Thorvilson

DEPARTMENT OF NATURAL RESOURCES AND CONSERVATION, HELENA, MT.

Jack Acord

Steve White

Tom Patton

SANITARIANS REPRESENTING THE FOLLOWING COUNTIES:

Beaverhead	Lincoln
Broadwater	Madison
Cascade	Musselshell
Deer Lodge	Petroleum
Fergus	Pondera
Golden Valley	Powell
Granite	Ravalli
Jefferson	Sanders
Judith Basin	Teton
Lewis and Clark	Wheatland

U.S. Forest Service

Beaverhead National Forest

Supervisors Office, Dillon, MT.
Dillon Ranger District, Dillon, MT.
Wise River Ranger District, Wise River, MT.
Wisdom Ranger District, Wisdom, MT.
Sheridan Ranger District, Sheridan, MT.

Bitterroot National Forest

Supervisors Office, Hamilton, MT.
Darby Ranger District, Darby, MT.
Stevensville Ranger District, Stevensville, MT.
Sula Ranger District, Sula, MT.
West Fork Ranger District, Darby, MT.

Deerlodge National Forest

Supervisors Office, Butte, MT.
Deer Lodge Ranger District, Deer Lodge, MT.
Jefferson Ranger District, Whitehall, MT.
Philipsburg Ranger District, Philipsburg, MT.
Butte Ranger District, Butte, MT.

Flathead National Forest

Swan Lake Ranger District, Bigfork, MT.
Condon Work Cnter, Condon, MT.

Gallatin National Forest

Big Timber Ranger District, Big Timber, MT.
Bozeman Ranger District, Bozeman, MT.
Gardiner Ranger District, Gardiner, MT.
Livingston Ranger District, Livingston, MT.

Helena National Forest

Supervisors Office, Helena, MT.
Townsend Ranger District, Townsend, MT.
Helena-Canyon Ferry Ranger District, Helena, MT.
Lincoln Ranger District, Lincoln, MT.

Kootenai National Forest

Fortine Ranger District, Fortine, MT.
Libby Ranger District, Libby, MT.
Rexford Ranger District, Eureka, MT.
Cabinet Ranger District, Trout Creek, MT.
Fisher River Ranger District, Libby, MT.
Troy Ranger District, Troy, MT.
Yaak Ranger District, Troy, MT.

Lewis and Clark National Forest

Supervisors Office, Great Falls, MT.
Teton Ranger District, Choteau, MT.
Sun River Ranger District, Augusta, MT.
Belt Creek Ranger District, Neihart, MT.
Judith Ranger District, Stanford, MT.
Musselshell Ranger District, Harlowton, MT.
White Sulphur Springs Ranger District, White Sulphur Springs, MT.

Lolo National Forest

Supervisors Office, Missoula, MT.
Missoula Ranger District, Missoula, MT.
Ninemile Ranger District, Huson, MT.
Plains Ranger District, Plains, MT.
Seeley Lake Ranger District, Seeley Lake, MT.
Superior Ranger District, Superior, MT.
Thompson Falls Ranger District, Thompson Falls, MT.

Regional Offices

Northern Region, Missoula, MT.
Rocky Mountain Region, Denver, CO.
Intermountain Region, Ogden, UT.
Pacific Northwest Region, Portland, OR.

Forest and Range Experiment Stations

mountain, Ogden, UT.
nountain, Logan, UT.
nountain, Moscow, ID.
ountain (Forestry Sciences Lab), Missoula, MT.
Northwest, Portland, OR.
c Northwest, Corvallis, OR.
c Northwest, Seattle, WA.
Mountain, Ft. Collins, Co.
Mountain, Bottineau, ND.
untain, Tempe, AZ.